Best Practice Guideline for conducting Life Cycle Assessment (LCA) studies in South Africa

Guideline 1 in the CSIR's LCA Guideline Series

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List of Acronyms

Acronym	Description
ALCA	Attributional Life Cycle Assessment
CLCA	Consequential Life Cycle Assessment
E-LCA	environmental Life Cycle Assessment
EPD	Environmental Product Declaration
EPR	Extended Producer Responsibility
EF	Environmental Footprint
EoL	End of Life
GLAD	Global LCA Data Access
GLAM	Global Guidance for Life Cycle Impact Assessment Indicators and Methods
IA	Impact assessment
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
LCSA	Life Cycle Sustainability Assessment
LCT	Life Cycle Thinking
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rule
PCR	Product Category Rule
SCP	Sustainable Consumption and Production
SDGs	Sustainable Development Goals
SETAC	Society of Environmental Toxicology and Chemistry
TGH	The Green House
UCT	University of Cape Town
UKZN	University of Kwa-Zulu Natal
UNEP	United Nations Environment Programme
WITS	University of Witwatersrand

Glossary

Allocation

Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems (ISO, 2006b).

Background system (or dataset)

The background system consists of processes on which no or, at best, indirect influence may be exercised by the decision-maker for which an LCA is carried out. Such processes are called "background processes" (Frischknecht, 1998).

Dataset (LCI or LCIA)

A document or file with life cycle information for a specified product, site or process; covering descriptive metadata and quantitative life cycle inventory and/or life cycle impact assessment data, respectively (European Commission – Joint Research Centre – Institute for Environment and Sustainability 2009).

Endpoint indicator

Endpoint indicators represent the potential damage to areas of protection / concern (e.g. human health, ecosystems or resource availability), as a result of environmental impacts (see also "Midpoint indicator".

Foreground system (or dataset)

The foreground system consists of processes which are under the control of the decision-maker for which an LCA is carried out (foreground processes) (Frischknecht 1998).

Hotspot

A life cycle stage, process or elementary flow which accounts for a significant proportion of the environmental impact of the functional unit.

Hotspot Analysis

A type of analysis used to identify and prioritise potential interventions around the most significant environmental impacts or benefits associated with a specific stage(s) in the product life cycle. Hotspot analysis is often used as a precursor to developing more detailed or granular sustainability information.

Impact category

An Impact Category refers to a class or group representing environmental issues of concern (e.g. climate change, water depletion) to which life cycle impacts can be assigned (ISO, 2006b).

Life Cycle

Consecutive and interlinked stages of a product system, from raw material acquisition to final disposal (ISO, 2006b).

Life Cycles approaches

A set of techniques and tools for assessing the impacts across a product's life cycle.

Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a systematic approach that evaluates the environmental impacts of a product throughout its entire life cycle, from extraction of raw materials through to final disposal.

Life Cycle Impact Assessment (LCIA)

Phase of Life Cycle Assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system throughout the life cycle of the product (ISO, 2006b).

Life Cycle Inventory (LCI)

The phase of Life Cycle Assessment where data are collected, the systems are modelled (dataset building), and the LCI results are calculated.

Life Cycle Inventory database

A system intended to organize, store, and retrieve large amounts of digital LCI datasets easily. It consists of an organized collection of LCI datasets that completely or partially conform to a common set of criteria, including methodology, format, review, and nomenclature. Databases also allow for interconnection of individual datasets that can be specified for use with identified impact assessment methods in application of LCA and LCIA.

Life Cycle Inventory datasets

A set of input and output data relating to a specific process. Usually, an inventory dataset also contains metadata describing, for example, geography, time reference, and ownership of the dataset. Processes can refer to unit processes or aggregated (system) processes.

Life Cycle Models

Description and/or graphical depiction of life cycle stages constituting the life cycle of a product (or service).

Midpoint indicator

Midpoint indicators represent environmental impacts of a certain type, but don't necessarily predict the ultimate effects on areas of protection / concern (e.g. human health or ecosystems) – refer also to "Endpoint indicator".

Producer(s)

In the context of this Guideline, "Producers" refers to producers, brand owners and importers of identified products in the EPR Regulations and Notices (DFFE, 2021).

Product Life Cycle

In this context, the product life cycle consists of all the direct and supporting processes (see "product system") required to build, distribute, use, maintain, and retire a product, from extraction of raw materials to their final disposal or recycle, i.e. cradle to grave.

Product System

ISO defines product systems as a collection of materially and energetically connected unit processes, which perform one or more defined functions. The term "product" used alone includes not only product systems but can also include service systems.

Reference Flow

Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit (ISO, 2006b).

Reference product

Product of an activity for which a change in demand will affect the production volume of the activity (also known as the determining products in consequential modelling) (Weidema et al. 2011).

Secondary Packaging (as per the EPR Regulations (DFFE, 2020))

Packaging that typically contains products already packaged in primary packaging.

Secondary Raw Material

A secondary raw material is a substance or material recovered from process residuals or from end-of-life products that can be used in manufacturing processes instead of or in combination with virgin raw material.

System Boundary

Set of criteria specifying which unit processes are part of a product system (ISO, 2006b).

Unit process

Smallest element considered in the life cycle inventory analysis for which input and output data are quantified (ISO, 2006b).

Value Chain

A value chain is a high-level model describing the activities of a firm operating in a specific industry to receive raw materials as input, add value to the raw materials through various processes, and deliver finished products to customers.

1 Why these Guidelines?

Globally, there is a growing intent to regulate environmental claims made in relation to products, and to harmonise reporting on 'Green' products to inform policy, producers and consumers. A number of South Africa's key trade partners (particularly the EU and USA) are introducing strict requirements for products entering their markets to report on their Product Environmental Footprint (PEF), or to make Environmental Product Declarations (EPDs).

Life Cycle Assessment (LCA) is the established methodology both for calculating a Product Environmental Footprint, and for making an Environmental Product Declaration. As such, both the PEF and EPD requirements imply that an LCA study must be undertaken.

At the same time, South Africa has recently published Extended Producer Responsibility (EPR) Regulations, which, among other things, require producers (defined to include brand owners and importers) in certain industries to conduct LCA studies for their products.

South African producers will therefore increasingly be required to conduct LCAs on their products; in order to gain access to international markets, improve their competitiveness in these markets, and to meet regulatory requirements in SA.

However, there is a shortage of the required LCA capacity and data in SA; and a lack of guidance on how LCAs should be conducted in order to meet these various requirements. Furthermore, despite the existence of ISO standards 14040 (ISO, 2006a) and 14044 (ISO, 2006b); these provide only a general framework, and leave room for interpretation on numerous methodological issues. The flexibility offered by these main standards, as well as the wide range of additional possible applicable standards for different purposes, can make it difficult to navigate the LCA landscape.[1] It also leads to variations in the implementation of LCA, and a lack of consistency and validity in the resulting environmental claims.

To address these challenges, ongoing efforts are being made to standardize and harmonize LCA practices. For example, the European Commission's PEF methodology, and the associated Product Environmental Footprint Category Rules (PEFCRs) (European Commission, 2017b), offer a good example of a harmonious and standardised approach, with clearly defined requirements to follow to ensure consistency among studies.

This Guideline is intended to provide guidance to South African producers on how to conduct LCA studies in accordance with both the EPR Regulations and export market requirements. Similarly to the PEF approach, the intention is to provide a standardised set of recommendations regarding the various methodological choices that need to be made when conducting an LCA study. Ultimately, the intention is

[1] Refer to *Guideline 2 – Relevant Standards* for a full list of possible applicable standards relating to LCA studies.

to ensure that LCA studies in South Africa are conducted in such a way as to ensure relevance, consistency, completeness, comparability and transparency.

The Guideline was developed based on an extensive review of available standards, data and methods, as well as international experiences in the development of such guidelines; and in consultation with relevant South African experts and stakeholders. The aim was to build on (rather than replicate) existing knowledge and tools, and to provide up-to-date information to ensure alignment with global initiatives, while being tailored to the South African context.

The aims of this Guideline are to:

- **Develop a clear set of methodological choices and recommendations for conducting LCA studies** in accordance with South Africa's EPR Regulations (Regulation 5, sub-regulations (1)(k) and (1)(l)) (DFFE, 2021);
- **Provide guidance for producers to comply with export market requirements** (e.g. the EU and US);
- **Harmonise, wherever possible, among these different standards and requirements,** so as to avoid duplication and capitalize on synergies.

2 Who is it for?

This Guideline is aimed primarily at **producers** (including brand-owners and importers) and **Producer Responsibility Organisations (PROs)** needing to conduct LCA studies in terms of either the EPR Regulations or export market requirements (such as PEF or EPD requirements); as well as **LCA practitioners.**

In particular, Regulation 5, sub-regulations (1)(k) and (1)(l) of the EPR Regulations (DFFE, 2021) require producers, brand owners and importers of identified products (see below) to undertake LCA studies (see Box 1):

Box 1: Requirements of the EPR Regulations in terms of Life Cycle Assessment

"5. (1) The producer of a product or class of products, as identified by the Minister in terms of section 18(1) of the Act, must-…

(k) conduct a life cycle assessment, in relation to the product, in accordance with the applicable standards within 5 years of implementation of their extended producer responsibility scheme;

(l) through the life cycle assessment as a minimum focus on the following:

(i) Minimisation of material used in the identified product;

(ii) Design of the product to facilitate reuse; recycling or recovery, without compromising the functionality of the product; and

(iii) Reduction of environmental toxicity of the resulting post -consumer waste stream."

To date, producers in six sectors have been identified by the Notices accompanying the EPR regulations:

- Published on 5th November 2020:
    - Paper, packaging and some single use products
    - Lighting
    - Electrical and electronic equipment
- Published on 23rd March 2023:
    - Portable batteries
    - Lubricant oils
    - Pesticides.

Section 4 of this Guideline provides some general recommendations regarding the appropriate level at which LCA studies should be conducted within each of these sectors.

Policymakers are referred to a policy brief recently published by UNEP's Life Cycle Initiative (UNEP, 2024), which provides guidance on the use of LCA to inform policy, and on evaluating the robustness of an LCA study. The recommendations provided in the current Guideline align with the Policy Brief in terms of what constitutes a robust LCA study.

3 Why do the EPR Regulations require that LCA studies must be conducted?

The LCA requirement in the EPR Regulations is intended to ensure greater circularity of products and materials in the long term. Specifically, LCA studies conducted in accordance with the EPR Regulations are required to focus on at least the following three aspects:

1. "*Minimisation of material used in the identified product*": This can be interpreted primarily as a requirement to reduce the use of virgin materials; while it could also be extended to include reduction in the use of toxic materials and materials which are difficult to deal with post-use.
2. "*Design of the product to facilitate reuse; recycling or recovery*": This is intended to ensure that products are reusable or that the materials can be more easily recovered for recycling through appropriate design; and to ultimately foster a sustainable market for secondary materials.
3. "*Reduction of environmental toxicity of the resulting waste stream*": This could be achieved by avoiding the use of toxic materials and chemicals of concern, and exploring alternatives.

The focus of the LCA requirement in the EPR Regulations is therefore on improved product design to enable circularity; specifically, to ensure that:

- Products are designed to be reused, recovered and recycled easily
- Products and materials are recovered at the highest rate possible; and
- materials are kept within the economy at the highest possible value.

The LCA requirement of the EPR Regulations should therefore be considered in combination with the EPR targets (which are also intended to drive upstream solutions for enhancing circularity), as well as with other elements in the EPR Regulations, such as the potential formulation of eco-modulated EPR fees; as these elements will all inform each other.

For example, the EPR targets set by Government for collection, recycling, reuse and recycled content could be used as a basis to inform alternative scenarios to be explored by the producers/brand owners within LCA studies. The insights gained through the LCA should then be used to inform the design of products and of end-of-life management systems in such a way as to enable the targets to be met. In this way, LCA studies can contribute meaningfully towards the successful implementation of EPR in South Africa.

In the long term, the results of LCA studies could also be used to inform eco-labelling and environmental claims, as well as helping PROs to define eco-modulated EPR fees; e.g. through a potential scoring system (as applied in the EU). Figure 1 shows how some of these elements in the EPR regulations link to each other and how they could inform each other.

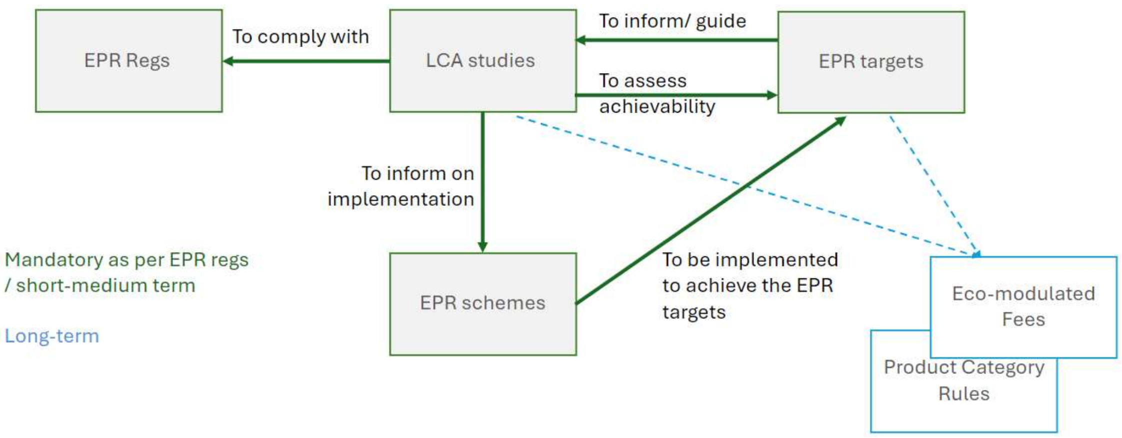

Figure 1: Linkages between key elements in the EPR Regulations, with specific reference to the LCA requirement (Source: Authors)

4 Can products be "grouped" to fulfil the requirements of the EPR Regulations?

LCA studies are costly and time-consuming. Given the large number of products identified in the Notices to the EPR Regulations, the number of producers of each product, the limited number of LCA practitioners in SA, and the lack of relevant South African LCA data; it will be costly and impractical to expect each producer to conduct LCA studies on each and every product within the required timeframes.

We propose an approach which will enable producers to comply with the LCA requirement of the EPR Regulations in the most efficient and cost-effective way; while ensuring that LCA studies are robust and scientifically credible, and that the results are meaningful.

4.1 Principles

The proposed approach is based on three principles:

1. **Scaling** – to enable variations in size / mass of a product to be assessed in a single LCA study.
2. **Scenario analysis** – to enable variations in product design (e.g. different colours, materials, additives, delivery systems etc.) to be assessed in a single LCA study.
3. **Collective approach** – to enable different producers of a similar product to collectively commission a single LCA study, provided that variations in size and design are accounted for through Scaling and Scenario analysis.

Consider the example of a producer of PET beverage bottles, who produces such bottles in various sizes (e.g. ranging from 500ml to 2 liters) and colours. Instead of conducting a separate LCA study on each variation; such variations can be incorporated within a single LCA study, and addressed through Scaling and Scenario Analysis. This will also enable comparability in terms of the environmental impact associated with different design choices, and will therefore yield information to inform improved design.

1. SCALING

A UNEP meta-analysis of LCA studies on single-use plastic bags and their alternatives concluded that "*The material type and weight of a shopping bag are important characteristics for determining its environmental impacts". This implies that "A bag with the same material but double the weight has double the impact, unless it is reused more times or used to carry more goods*" (UNEP, 2020)[2].

The above concept can similarly be extended to other products, including many of the product classes identified in the EPR notices. In particular, the concept can be easily applied to many mono-material and multi-layer products, including those identified in the EPR Notice for "*Paper, packaging and some single use products*". It can also potentially be applied to products whose formulation can be dealt with on a mass basis, such as *pesticides* and *lubricant oils*[3]. Some additional complexities may arise in the case of the *lighting*, *portable batteries* and *electronic and electrical equipment* sectors; but it is likely that these could be resolved on a case-by-case basis through discussion between the relevant PROs, producers and LCA experts (see below).

In the case of PET beverage bottles, for example, the general finding above suggests that a single LCA study can be conducted, with results **scaled up or down** for different sizes. This could be done in one of two ways:

(a) Conduct the LCA study on a defined quantity of the product (e.g. 1 kg or 1 tonne of PET material); with the results scaled up or down to the actual material weight of each variation.
(b) Conduct the LCA study on a representative product (e.g. a 1 litre PET beverage bottle), with the results scaled up/down to the different variations (e.g. scaled down in the case of the 500ml bottle, and up for the 2L bottle).

A caveat is that secondary packaging[4] must also be taken into account; as this could potentially outweigh the primary packaging (in terms of mass and environmental impact). If secondary packaging is excluded, there is a risk of finding the 'wrong' trend with respect to pack sizes (for example, small sizes can look favourable in terms of primary packaging; but this is not necessarily true when secondary packaging is taken into account).

[2] United Nations Environment Programme (UNEP), 2020. Single use plastic bags and their alternatives. Recommendations from Life Cycle Assessment.
[3] To be verified with the respective PROs.
[4] Please refer to the **Glossary**.

2. SCENARIO ANALYSIS

Certain design choices or product characteristics can affect how easily and (cost-)effectively a product can be recovered and recycled at end of life, or the available options for use of the secondary material in new products. Some characteristics could either favour effective recovery and recycling, and thereby enable EPR targets to be met; while other characteristics may hinder effective recovery and recycling. For example, the use of certain colours, materials or additives could impact on recyclability, and therefore on the ability to meet recycling rate targets.

Such characteristics should be explored through **Scenario Analysis**, in order to inform redesign of products in such a way as to enable the EPR targets to be met. This would enable an assessment of the impacts of alternative scenarios (e.g. the use of different colours, materials or additives) on the results; thereby informing product redesign in such a way as to enable the EPR targets to be met (see Section 0 for more details regarding scenario analysis in the context of LCA studies).

3. COLLECTIVE APPROACH

Even if the Scaling and Scenario Analysis principles are applied, in many cases it may still be impractical for each and every producer of the same class of products to conduct a separate LCA study.

A third principle that could be applied is that of a **Collective Approach**, in which multiple producers of a similar product (e.g. PET beverage bottles) could combine their resources to commission a single LCA study (perhaps coordinated through the relevant PRO). Again, in this collective approach, the principles of Scaling and Scenario Analysis should be applied, to ensure that all variations of the product across the multiple producers are covered within the LCA study.

In addition:

- Minimum requirements should be established for participation in a collective LCA
- Providing data and participating in key decisions regarding the approach; to ensure that the representative product and its variations are indeed representative.
- The representative product could potentially be used for benchmarking. Participants in the Collective LCA could have the performance of their specific product assessed against the benchmark (this information need not be disclosed publicly)
- Furthermore, Sensitivity Analysis (see section 7.4) is recommended to test robustness of the results to variations in key input data.

4.2 At what level should LCA's be conducted?

The annexures to the EPR Notices identify specific products or classes of products, with five-year targets set for each product or product class. In general, we would propose that one LCA study be conducted per product class, through application of the above principles. This would help to ensure alignment between the LCA studies and EPR targets, and would be a more practical and meaningful approach as compared to each producer conducting a separate LCA study for every variation of their product.

In some cases, however, it may be possible for a single LCA study to cover a number of product classes (e.g. where products within different product classes have similar characteristics); while in other cases, more than one LCA study may be required for a single class of products (e.g. in cases where products within a single product class have very different characteristics). It is recommended that producers and PROs engage with relevant LCA experts to determine the appropriate level at which LCA studies should be conducted for each class of products.

A general recommendation that can be drawn from the principles discussed above is that:

- A single LCA study should be conducted (collectively, if possible) for each class of products identified in the EPR Regulations.
- The LCA should be conducted for a specified quantity (mass), or for a representative product that best represents the class of products; and results scaled up/down for different variations.
- Include secondary packaging (see **Glossary**), when this is part of the product sold/delivered.
- A Scenario Analysis should be conducted on at least the following aspects:
    - The impact of different design characteristics (e.g. the use of mixed materials, colours, binders, fillers and other additives) on production, recovery and recycling of the material.
    - How variations in the type and quantities of raw material used can influence the environment impacts.
    - How differences in other key parameters, such as electricity supply and transport of the materials/products, affects the results.

However, these general recommendations would need to be unpacked and confirmed on a case-by-case basis for each product class; through discussions between the relevant PROs, producers, LCA experts, and technical experts on the products/materials in question.

5 How to use this Guideline

This Guideline forms part of an **LCA Guideline series**. *Guideline 1* (the current guideline) is the main guideline, providing information on how to conduct an LCA study in the South African context.

Guideline 1 is structured as follows:

- Section 6 introduces the concept of Life Cycle Assessment; as well as other approaches based on Life Cycle Thinking. Additional information can be found in Annexure 1; as well as in *Guideline 2* and *Guideline 3* (see below).
- Section 7 presents recommendations on modelling choices associated with the various stages of conducting an LCA; and is therefore the core of this Guideline.

Further information on certain aspects can be found in the accompanying guidelines, as follows:

- *'Guideline 2: Relevant standards'* provides a full list of possible applicable standards to be used to conduct LCA studies. The relevant standard to be followed will depend on the goal and scope of the study in each case (see Section 0.1).
- *'Guideline 3: Summary of available PCRs and PEFCRs'* provides a (non-exhaustive) list of Product Category Rules (PCRs) and Product Environmental Footprint Category Rules (PEFCRs) which may be relevant to the products identified under the EPR Notices (DFFE, 2021).
- *'Guideline 4: Templates for LCA Reports and for Critical Reviews of LCA Studies* provides suggested templates both for LCA study reports; and for critical reviews of LCA studies, in cases where such reviews are required (see Section 7.4.3).

In addition to these Guidelines, it is also recommended that LCA training be undertaken. LCA training is typically provided in the use of a specific LCA software tool. For acronyms and definitions of technical terms, please refer to the **Acronyms** and **Glossary** lists at the beginning of this Guideline.

Additional resources can be found at the following websites:

- **The International Organisation for Standardisation (ISO - International Organization for Standardization)** is responsible for publishing the main LCA standards referred to in this Guideline series (ISO 14040 and 14044). Locally, **the South African Bureau of Standards (SABS)** republishes these ISO standards. Refer to *Guideline 2: Relevant standards* for a comprehensive list of relevant standards to conduct LCA studies, as well as links to relevant websites.
- **PRé Sustainability** is a provider of one of the main LCA software tools (see Section 7.2.2). It also offers theoretical resources on key LCA concepts - see Articles - PRé Sustainability (pre-sustainability.com)
- **ecoinvent** is a provider of one of the largest global LCA Databases (most often integrated within LCA software tools). It also provides users with technical knowledge (see ecoinvent Database - ecoinvent); as well as scientific knowledge (Publications - ecoinvent).
- **The international EPD system** (PCR Library | EPD International (environdec.com)) contains a repository for both Product Category Rules (PCRs) and Environmental Product Declarations (EPDs), and is constantly updated on the latest developments.
- **The EU Product Environmental Footprint** system has created, and constantly improves and expands, its own methodology (PEF), LCI datasets and PCRs, called Product Environmental Footprint Category Rules (PEFCRs) - see Single Market for Green Products - The Product Environmental Footprint Pilots - Environment - European Commission (europa.eu). When conducting a PEF study, a relevant PEFCR can provide key guidance on how to conduct the study so as to be compliant with the PEF methodology.
- **The American Centre for Life Cycle Assessment (ACLCA)** has developed its own guidance document for development of PCRs (Ingwersen and Subramanian, 2014), as well as an ACLCA PCR Guidance: Process and Methods Toolkit (available at PCR - ACLCA).

Information on other entities in specific countries which take the lead in the development of LCA building blocks, as well as in promoting the use and uptake of LCA, can be found in *Guideline 2*.

6 Life Cycle Assessment and other life cycle-based tools

6.1 Introduction to Life Cycle Assessment

In line with the Sustainable Development Goals (SDGs), and particularly SDG 12 (sustainable consumption and production); decisions by both producers (e.g. regarding product design and production processes) and consumers should take into account the economic, social and environmental consequences of products throughout their life cycle.

Life Cycle Assessment (LCA) is a systematic approach that evaluates the environmental impacts of a product throughout its entire life cycle (see Figure 2), from extraction of raw materials through to final disposal.

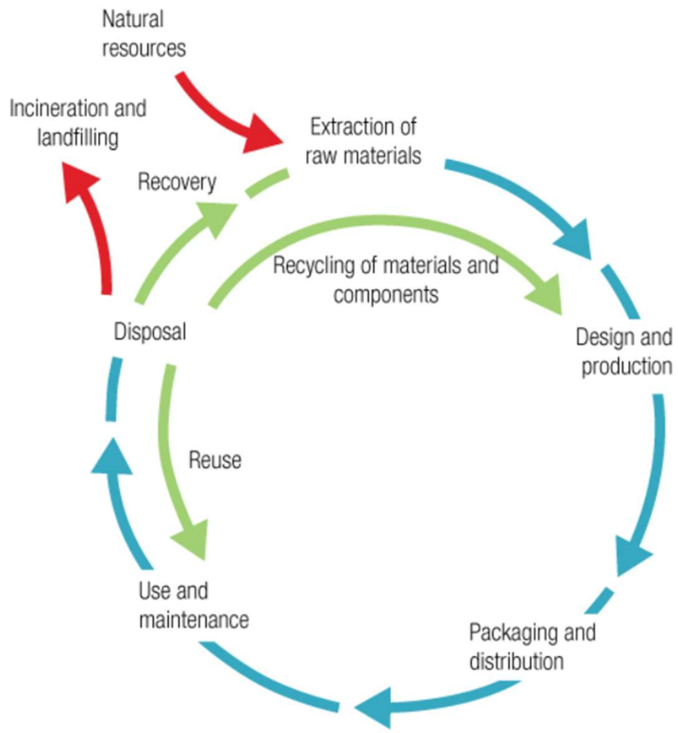

Figure 2: A typical Product Life Cycle (Source: UNEP/SETAC Life Cycle Initiative). The red arrows indicate resource use and disposal (typical features of a linear economy), while the green arrows show how this can be avoided or delayed in a circular economy.

The development of LCA can be traced back to the 1960s and 1970s, when environmental concerns began to emerge as a result of industrialization and increased resource consumption. Researchers and scientists recognized the need for a comprehensive method to assess the environmental performance of products and processes. The Society of Environmental Toxicology and Chemistry (SETAC) and the International Organization for Standardization (ISO) were instrumental in developing LCA as a standardized methodology.

LCA quantifies the inputs of material and energy resources, as well as outputs of emissions and waste, throughout a product's life cycle – including raw material extraction, manufacturing, packaging and distribution, use and maintenance, and end-of-life disposal. An LCA considers various environmental impact categories in the assessment; including the consumption of energy, land, water and other resources; as well as various types of emissions to air, water and soil.

LCA enables the identification of impact 'hotspots' along the product life cycle; and helps to make informed decisions to minimize environmental impacts, optimize resource efficiency, and promote the transition towards a circular economy. By conducting LCAs, companies and policymakers can identify opportunities to reduce the environmental footprint of products and processes, enhance resource efficiency, and promote the use of renewable materials and clean technologies. In short, LCA contributes to the development of sustainable consumption and production, by informing decision-making, fostering innovation, and driving continuous improvement.

The holistic nature of LCA is a central aspect. Some key features that underpin any LCA study include:

1. **Life Cycle focus:** all stages in the life cycle of the product are considered; from raw material extraction, to processing and manufacturing, distribution, use, and end of life. The duration of a product's lifetime significantly influences its environmental performance.
2. **Multi-criteria analysis:** multiple environmental categories are included in the analysis; i.e. a range of environmental impacts of the product are considered. Single-issue studies (e.g. carbon footprints, water footprints) also fall under the broad umbrella of LCA; however, a full LCA study would typically consider many different environmental impact categories.
3. **Quantitative methodology:** indicators are quantitative and based on mathematical models describing the cause-effect relationships deriving from different stressors (e.g. use of natural resources, or emissions to the environment). LCA requires quantitative data across the whole product life cycle to quantify how much of different types of resources are consumed, and how much of different types of pollutants are emitted.
4. **Comparative approach:** Given its quantitative nature, LCA is designed to allow the choice of the best option among two or more scenarios/alternatives. The comparison can be between products that fulfil the same purpose, or between scenarios (e.g. new design, new sources of raw materials, or different end of life options) for the same product.
5. **Global extension:** the analysis can be adapted to systems extending from the local to the global scale.

Box 2: Overarching aim of Life Cycle Assessment

The overarching aim of an LCA study is to assess and improve the entire system, and thereby avoid decisions that fix one problem, but give rise to other unexpected environmental issues (shifting of burdens). Burden shifting can refer to the shifting of the environmental burden (impact) from one stage in the life cycle to another, from one impact category to another, and/or from one country to another.

6.2 Life cycle approaches and decision support tools

Life Cycle Assessment, as well as related approaches such as Product Environmental Footprint and Environmental Product Declarations, are all based on Life Cycle Thinking.

Life cycle thinking (LCT) is about going beyond the traditional focus on specific production sites or manufacturing processes; towards understanding resource use and emissions over the entire product life cycle**.** Over the years, LCT has provided a conceptual basis for the development of a series of life cycle-based approaches and tools aimed at assisting with decision-making at all levels regarding product development, production, procurement and final disposal. A number of decision support tools based on LCT exist, some of which are illustrated in Figure 3.

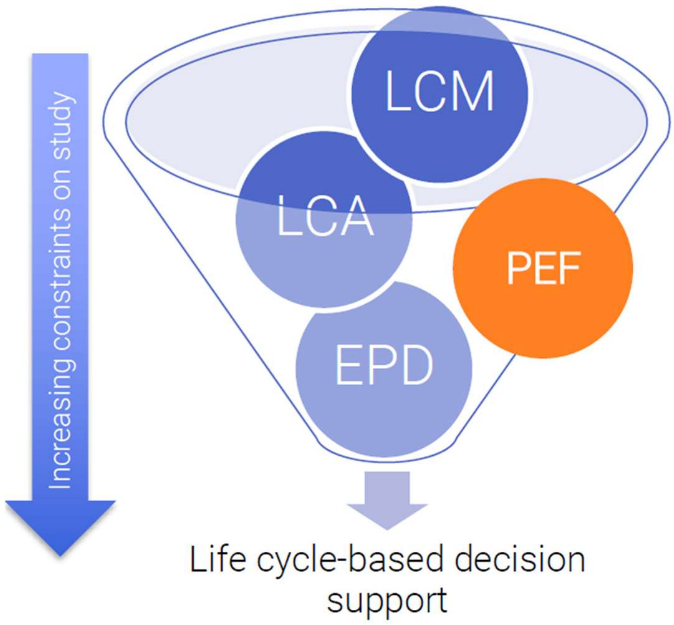

Figure 3: Life cycle-based decision support tools
(Source: TGH presentation at 1st Stakeholder Engagement, Oct 2022)

Life Cycle Management (LCM) is a business management strategy based on Life Cycle Thinking, aimed at ensuring improved sustainability performance across the product life cycle. Essentially, LCT is made operational through LCM. For more information on LCM, please see the Life Cycle Initiative website at [Reports & Training Materials - Life Cycle Initiative].

Life Cycle Assessment (LCA) is a well-known and time-tested methodology to evaluate the environmental impacts associated with all stages in the life cycle of a product (good or service).

The ISO 14040 series (Table 1) provides specific requirements and guidelines for conducting LCA studies. Specifically:

- ISO 14040 (ISO, 2006a) provides the “principles and framework” for LCA, and is intended for a managerial audience;
- ISO 14044 (ISO, 2006b) provides an outline of the “requirements and guidelines” for conducting LCA studies, and is meant for practitioners.

The ISO standards provide a standardised structure and general principles for conducting LCA studies. However, these standards leave room for flexibility and interpretation. Methodologies, data sources, and assumptions can vary widely. Different decisions regarding data collection, modelling, and impact assessment methodologies can lead to very different results.

In order to address these obstacles and improve the consistency and validity of environmental claims, a number of initiatives have attempted to harmonize LCA practices. Chief among these are **Environmental Product Declarations (EPDs)** and the EU’s **Product Environment Footprint (PEF)** initiative (see Figure 3). Annexure 1 provides more information on these two initiatives, and compares them with the standard LCA approach.

In addition, the need to create EPDs that are ISO-conformant and consistent with LCA best practices is also recognised by the **American Centre for Life Cycle Assessment (ACLCA)**, which has developed its own set of requirements. These efforts at standardisation and harmonisation are aimed at enhancing the credibility of environmental claims and enabling producers, consumers and policymakers to make informed decisions based on comparable, reliable data.

For a comprehensive list of additional relevant standards for conducting LCA studies, refer to *Guideline 2: Relevant standards.*

LCA is also known as Environmental LCA (E-LCA). In addition to E-LCA, there are a number of other types of LCA studies; including:

- Social LCA (S-LCA) provides a standardized methodological framework that allows for assessment of social and socio-economic impacts along the life cycle of products and services (UNEP, 2020).
- Life cycle costing (LCC) is a product-related assessment that follows the LCA framework. It allows for assessing the economic performance (costs) of a product throughout its life cycle, identifying hotspots or points of improvement, and comparing the costs of products similar in function.
- Life cycle sustainability assessment (LCSA) attempts to combine E-LCA, S-LCA and LCC, in order to provide a more comprehensive assessment of products in terms of the environmental, social and economic pillars of sustainability.
- Carbon footprint (CF) and Water Footprint (WF) studies are essentially LCA studies conducted on a single indicator of interest.

However, regardless of the type of LCA, the procedure for the assessment (based on the ISO 14040 series) remains essentially the same (see Section 7).

Table 1: Overarching LCA standards (See also Guideline 2: Relevant Standards for a full list of applicable standards to LCA)

Standard Name	Description	Link to the standard
ISO 14040 (2006) – Environmental management – Life Cycle Assessment – Principles and framework	• Covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA • The intended application of LCA or LCI results is considered during the goal and scope definition, but the application itself is outside the scope of the standard	Available at ISO standards website (ISO 14040:2006 - Environmental management — Life cycle assessment — Principles and framework) Republished by SABS in SA (SANS 14040:2006 (Ed. 2.00) (sabs.co.za))
ISO 14044 (2006) - Environmental Management – Life Cycle Assessment – Requirements and guidelines	• Covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies • Replaces the old standards and can be used jointly with ISO 14040 • Specifies requirements and provides guidelines for LCA including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements	Available at ISO standards website (ISO 14044:2006 - Environmental management — Life cycle assessment — Requirements and guidelines) Republished by SABS in SA (SANS 14044:2006 (Ed. 1.00) (sabs.co.za))
ISO/TR 14047 (2012) - Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to impact assessment situation	• This Technical Report provides examples to support ISO 14044:2006. It uses several examples on key areas of ISO 14044 in order to enhance understanding of the requirements of the standard. • The examples only provide a sample of approaches to satisfying the provisions of ISO 14044, which are open to interpretation. They should not be seen as prescriptive of the many ways in which ISO 14044 could be interpreted and applied. • The examples also reflect the key elements of the life cycle impact assessment (LCIA) phase of an LCA. However, the examples are not exhaustive, and other examples exist to illustrate the methodological issues described.	Available at ISO standards website https://www.iso.org/obp/ui/en/#iso:std:iso:tr:14047:ed-2:v1:en
ISO/TR 14049 (2012) - Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis	• Similar to ISO/TR 14047, this Technical Report provides supplemental information to ISO 14044:2006, based on several examples on key areas of ISO 14044 in order to enhance understanding of the requirements. • With respect to the various phases of LCA, methodological requirements for conducting LCA studies are provided in ISO 14040 and ISO 14044.	Available at ISO standards website https://www.iso.org/obp/ui/en/#iso:std:iso:tr:14049:ed-2:v1:en

7 Methodological approach for conducting a Life Cycle Assessment

According to the ISO 14040 series, LCA studies are structured into four phases; although these should be conducted in an iterative way (see Figures 4 and 5):

1. Goal and scope definition: Involves stating the reasons and intended application of the study, defining key methodological choices, and clearly listing assumptions and limitations
2. Inventory analysis: involves both data collection and modelling of the product system
3. Impact assessment: the calculation of potential impacts associated with the impact category(ies) being investigated. Optional steps include normalisation and weighting of results
4. Interpretation – Involves presenting and interpreting the results of the study.

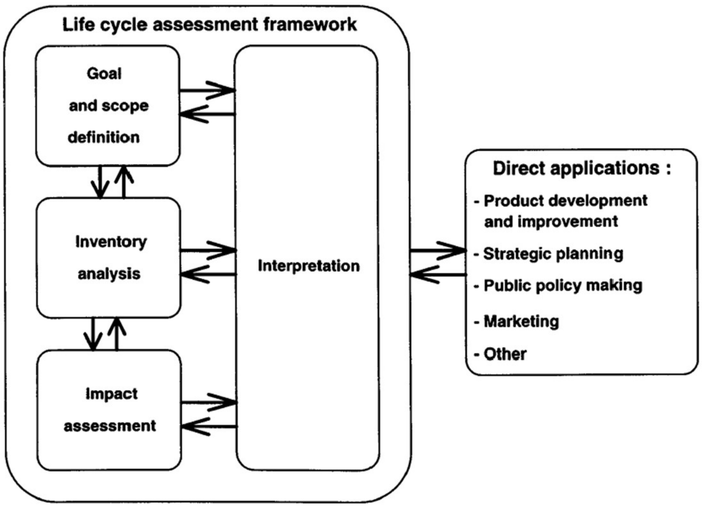

Figure 4: LCA framework as per the ISO 14040 series (Source: ISO 14040:2006)

This Section describes all the requirements and procedural steps to be followed to conduct an LCA study in accordance with ISO 14040 and 14044 (2006). It follows the four-stage approach outlined in Figure 4, and makes recommendations on specific methodological choices to ensure compliance with the EPR Regulations, while harmonising as far as possible with the PEF methodology. More detail on each of the four stages is provided in Sections 7.1 to 7.4.

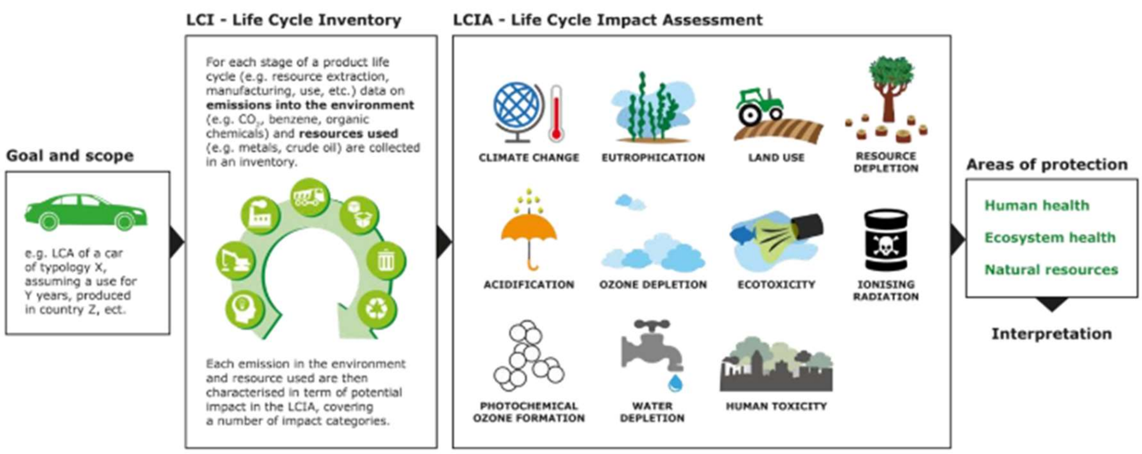

Figure 5: Steps in conducting an LCA study (Sala et al., 2016)

7.1 Goal and Scope Definition

Defining the goal and scope is the first step in undertaking an LCA study. As per ISO 14044 (2006), "*The goal and scope of an LCA shall be clearly defined and shall be consistent with the intended application. Due to the iterative nature of LCA, the scope may have to be refined during the study*".

7.1.1 Goal Statement

Stating the **goal** of an LCA study is essential to frame the structure and guide the decisions made in the latter stages of the assessment. According to ISO 14044 (ISO, 2006b), the goal statement should contain the following aspects:

- The intended application
- The reason/s for carrying out the study
- The intended audience.

In the South African context, the goal of an LCA study will be dependent on whether the study is being conducted to meet the requirements of the EPR Regulations, export market requirements (e.g. PEF), or for some other purpose (or a combination of purposes):

- For studies conducted to meet the requirements of the EPR Regulations; the goal should include the identification of the main drivers of impacts ("hotspots"), so that producers can improve the overall environmental performance of their products, with a specific focus on the three minimum requirements as per EPR Regulation 5, sub-regulation (1)(l) (see Box 1).
- For studies conducted to meet export market requirements, the LCA study would be based on the specific requirements of the market in question (e.g. PEF requirements in the case of products being exported to the EU, ACLCA requirements for products exported to the USA, etc.).

7.1.2 Function, Functional Unit and Reference Flows

Life Cycle Assessment can be used to evaluate the impacts of a diverse range of products and services. In any LCA study, it is necessary to specify the **function**, **functional unit**, and **reference flows** for the product system in question, in order to accurately construct and model the system, and to ensure comparability.

All products are manufactured to achieve one or more **functions,** by providing a service and fulfilling one or more customer needs (for example, the function of a lightbulb is to provide brightness).

The **functional unit** is defined as a quantified description of the performance of a product system, considering properties such as functionality, appearance, stability, durability, etc. (Weidema et al., 2004) (see Box 3 for examples).

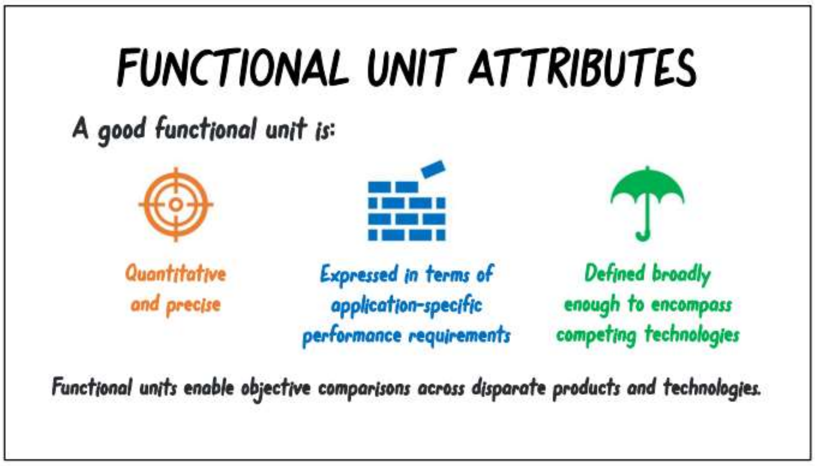

Figure 6: Key characteristics of a Functional Unit (Source: DOE (n.d))

After having defined the functional unit, **reference flows** translate this functional unit into specific material and energy flows for each of the product systems being studied, to enable comparison between various products (fulfilling the same function) on an equal basis. **As such, reference flows are the starting points for building the assessment model**.

Although the most commonly selected functional units are based on mass and volume, the choice of the functional unit is highly dependent on the goal of the study (Schau and Fet, 2008). Examples of functions, functional units and reference flows for some specific products falling under the EPR Notices are provided in Box 3.

Box 3: Examples of functions, functional units and reference flows for some products falling under the EPR Notices

Sector – Lighting

Example product: lightbulbs

Function: Provision of brightness

Functional Unit: Lighting 10 m^2 with 3000 lux with a spectrum of 3000K for 50 000 hours

Reference Flow: ~19 x 5 CFL warm white (3000K) bulbs of 30 000 lumen with a lifetime of 10 000 hours[5]

Sector – Packaging

Example product: beverage bottle

Function: To contain, protect and extend the lifetime of a beverage

Functional Unit: A bottle capable of holding and containing 500 ml of a beverage for 1 year

Reference Flow: xx[6] kg of packaging material needed

Sector – Portable Batteries

As per Porzio and Scown (2021), LCA studies on batteries should transition away from using kg of battery mass as a functional unit, and instead make use of kWh of storage capacity and kWh of lifetime energy throughput

Sector – Lubricants

Example product: lubricant oil

Function: Reduce friction and heating

Functional Unit: machining time of 1000 hours

Reference Flow: 1 or 5 or 20 kg/litre of base oil (to satisfy the function provided by the functional unit)

Sector – Pesticides

Example product: obsolete pesticides / co-formulant

Function: Mitigate harm from insects or weeds

Functional Unit: ha of treated farmland

Reference Flow: 1 or 5 or 20 kg chemical per 1 ha farmland

Sector – Electric and Electronic Equipment

This has to be case-specific due to the fact that the EPR Notice provides categories of WEEE classified only by their external dimensions.

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[5] Considering a CFL of 23 watts and considering that CFL bulbs have a lifespan of around 10,000 hours; to ensure lighting for 50,000 hours, one would need to replace the bulbs approximately 5 times over that period.

[6] xx equates to the amount of material needed to produce the bottle to able to perform the function.

7.1.3 System Boundary

The system boundary for an LCA study is a representation of which processes are included and excluded from the analysis. The system boundary must be specified in different dimensions (Tillman et al., 1994); including:

- boundaries between the system and nature
- demarcation of the geographical location
- the time horizon
- boundaries between the life cycle of the studied product and the life cycle of related products.

As with the functional unit, the choice of the system boundary is connected to the goal of the study. Although the boundaries for each system are unique, there are several generic ways of defining the boundaries for an LCA study, in terms of the stages of the life cycle that are included or excluded (see Figure 7):

- *Gate-to-Gate*: This boundary encompasses the operations at the manufacturing facility only. Intermediate flows cross the boundary, but the upstream and downstream processes are excluded. The scope of a gate-to-gate LCA study focuses on the inputs, outputs, and emissions that originate directly from the production process of interest.
- *Cradle-to-Gate*: This boundary is an extension of the gate-to-gate boundary in which all upstream processes, such as raw material extraction, are included. Downstream processes such as the end-of-life stage are still excluded from the scope of the study.
- *Cradle-to-Grave*: This is the most comprehensive type of boundary; as it includes all the stages of a traditional product life cycle, from raw material abstraction to the disposal and end-of-life stages, and everything in between.
- *Gate-to-Grave*: This boundary focuses on the use and end-of-life stages only.

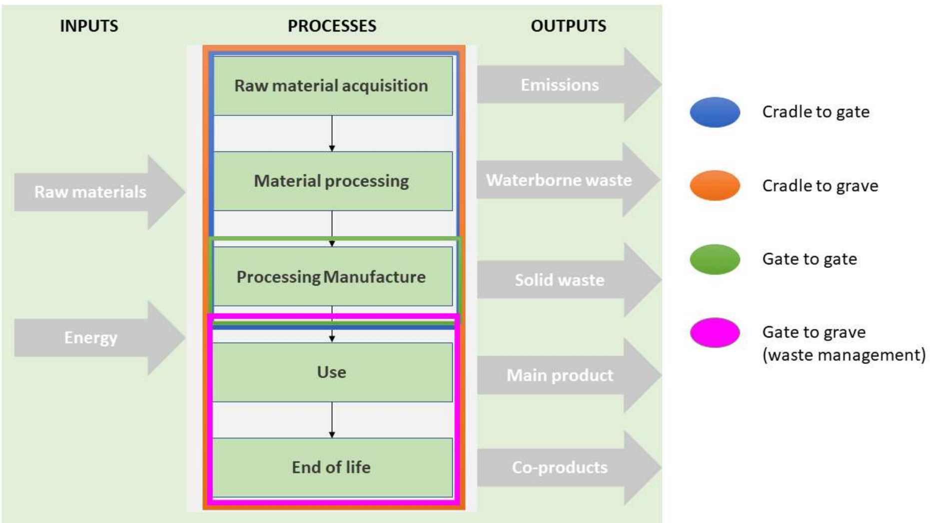

Figure 7: System boundaries (Source: Authors)

Best practice to follow:

- *For the purposes of compliance with the EPR Regulations, evaluate product systems with a cradle-to-grave boundary to account for all stages of the product life cycle.*
- *Use a Process Flow Diagram (PFD) to graphically depict the system boundary and to illustrate processes, life cycle stages and flows that are included and excluded.*

7.1.4 LCA approaches, allocation methods and system models

LCA approaches, **system models** and **allocation** (including allocation at end of life) are interlinked concepts. In each case, there are important choices to be made, which influence the results of an LCA study. These concepts are briefly introduced in the following sub-sections, and recommendations are made regarding appropriate choices in each case that are best aligned with the EPR Regulations. However, the choices made in each case should be consistent, due to the highly interlinked nature of the three concepts; and should be aligned with the **goal and scope** of the study.

7.1.4.1. LCA approaches

There are two main approaches to LCA, each of which focuses on answering a slightly different question (Ekvall, 2019):

- **Attributional assessments** focus on trying to understand the proportion of the total global environmental impact (for each impact category) that is attributable specifically to the product in question. They focus on answering the question, "What part of the global environmental burdens should be assigned to the product"? (Ekvall, 2019).
- **Consequential assessments** focus on trying to understand how making different decisions (e.g. changes in policy, or changes in the production or use of the product in question) affects the total global environmental impact. They try to answer the question, "What is the impact of the product on the global environmental burdens?" (Ekvall, 2019).

The choice between **attributional and consequential assessments** has an impact on various aspects of the study, including the system boundaries, the input data to be used in the calculations, and the End-of-life modelling. In most cases, **attributional LCA (ALCA)**, which is the simpler of the two approaches, can be used.

7.1.4.2. Allocation methods

A single production process often yields multiple outputs, including

- co-products (i.e. when a single production process yields more than one marketable product)
- by-products (such as wastes and recyclables).

These types of processes (in which more than one product is produced simultaneously) are referred to as **multi-output processes** or **multi-product activities**. In such cases, it would not be appropriate to assign all of the environmental impacts from the production system to a single product. Instead, **impacts must be apportioned (allocated)** among the various products, co-products, and by-products, including wastes and recyclables (Weidema, 2018, Schrijvers et al. 2016).

As with multi-product activities, **recycling** can also be seen as a multifunctional process: one function is to treat the waste, and the other function is to produce a new secondary raw material. As such, allocation is required in this case as well.

In LCA, this "**multifunctionality**" can be addressed by applying an allocation procedure. **Allocation** is the method applied in attributional LCA studies to deal with multi-product activities. It refers to the act of partitioning the input or output flows of a process between the product system under study, and one or more other product systems (ISO, 2006b).

The choice of both the **allocation approach**, and of the corresponding LCI database **system model** (see Section 7.2.3), is important; as it represents the manner in which the input and output flows of a process are divided between the product system under study and other systems (Williams and Eikenaar, 2022), which will ultimately impact on the results.

Choice of allocation method for multi-product activities

The ISO 14044 (2006b) standard, as well as the Product Environmental Footprint (PEF) methodology, suggest that, whenever possible, it is preferable to **avoid allocation** between product systems by performing **system expansion** (see Box 4); that is, to include the co-products or by-products within the system boundary under study.

As an alternative, when allocation cannot be avoided, the ISO standards recommend using **physical allocation**; i.e., using physical characteristics (such as the mass, volume, or energy content) of each co-product as a basis for allocation.

Finally, where physical relationship alone cannot be established or used as the basis for allocation, the third option is to apply **economic allocation**, that is, using the respective market prices of each product as a basis for allocation.

Box 4: Recommended allocation procedure as per ISO 14044:2006

"The study shall identify the process shared with other products systems and deal with them according to the stepwise procedure presented below:

a) Step 1: Wherever possible, allocation should be avoided by:
   i. Dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data to these sub-processes, or
   ii. Expanding the product system to include the additional functions related to the co-products, taking into account the requirements of (4.2.3.3)

b) Step 2: where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them: i.e. they should reflect the way in which inputs and outputs are changed by quantitative changes in the products or functions delivered by the system;

c) Step 3: where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products."

Choice of allocation method for recycling at end of life

The LCA requirement in the EPR Regulations requires producers to understand the impacts of their products throughout the full life cycle, including production, distribution, use, and end of life (**cradle-to-grave** – see Section 7.1.3).

When evaluating end-of-life scenarios, the **closed-loop approximation** method (also known as the **0/100 method** (Ekvall et al, 2020) is often an appropriate modelling choice; as it inherently uses system expansion to assess the impacts of recycling. This in turn best aligns with the ISO 14044 (2006b) recommendations (see Box 4), and with the intent of the EPR Regulations to make producers responsible for their products at the end of life.

This closed-loop approximation method incorporates:

a. the recycling of the product and the production of a new secondary raw material,
b. the waste treatments for the residual waste, and
c. avoiding of the production of the virgin material (see Figure 8).

The method assumes that recycled material substitutes for an equivalent amount of virgin material with the same inherent properties. The portion of virgin material avoided/substituted should be based on physical properties (e.g. mass, energy, etc.) and should take into account any changes in the inherent properties of the material that will be replaced (e.g. quality and performance).[7]

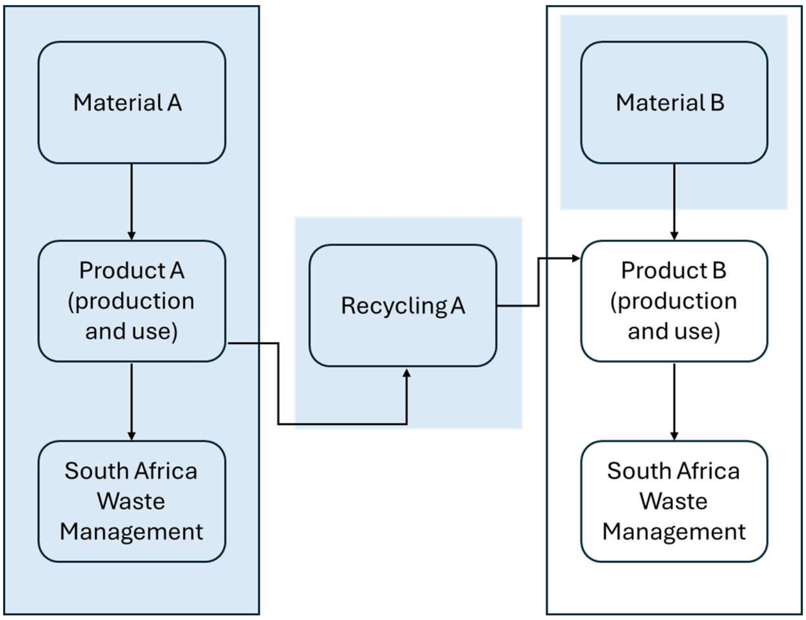

Figure 8: Representation of EoL allocation method for a product produced by System A which may be recycled and used in System B. Area shaded blue allocated to System A. Modelling of the waste management system takes into account the portion of the material that is not recycled. The Material B represents recyclate that can substitute for virgin material (Source: TGH LCA training material, adapted by the authors)

[7] https://thebatterypass.eu/assets/images/content-guidance/pdf/2023_Battery_Passport_EOL_Analysis.pdf

7.1.4.3. System models

The choices made regarding the LCA approach and allocation method (see above) also inform the selection of Life Cycle Inventory (LCI) **datasets** during the Inventory Analysis phase (see Section 7.2.3); and specifically, the **system model** on which the selected LCI datasets should be based (Section 7.2.3.4). As mentioned above, each of these choices should be aligned, and should serve the goal and scope of the study.

In LCA, **system models** play a key role in defining the boundaries and interactions of a product's life cycle; as they determine how processes are linked together, and how burdens are allocated in the case of processes that give rise to multiple products. These models establish the boundaries and interactions within a product's life cycle. Different system models apply different assumptions linking the distribution of impacts between producers and consumers (ecoinvent, n.d.)[8].

LCA databases provide datasets based on various different system models to meet the needs of different types of LCA studies (see Section 7.2.3). For example, in the **cut-off** system model, impacts associated with waste and waste treatment are allocated to the producer. This aligns with the closed-loop approximation method (see above), which inherently uses system expansion to assess the impacts of recycling; and with the intent of the EPR Regulations. In the ecoinvent database for example, the corresponding system model is called '**cut-off, by classification'** (ecoinvent, n.d.A).

Figure 9 summarises the suggested steps for selecting an appropriate allocation model, as well as the corresponding LCI datasets, for LCA studies conducted in the context of the EPR Regulations.

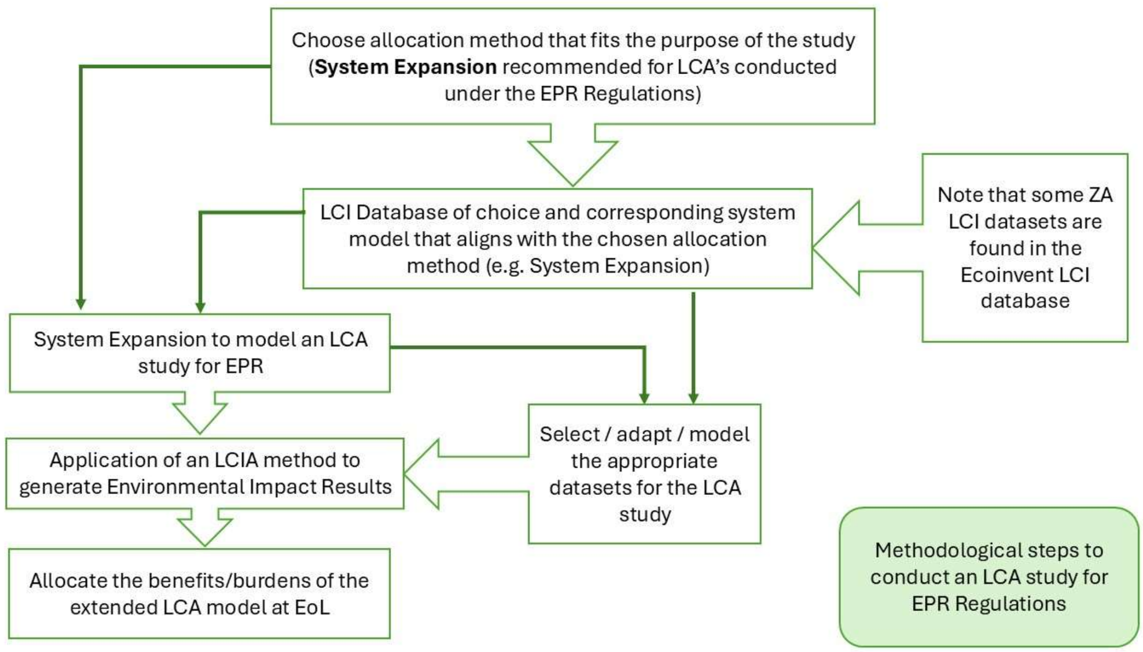

Figure 9: Suggested steps for choosing an allocation method and corresponding LCI datasets for LCA studies in the context of the EPR Regulations (Source: Authors)

[8] Ecoinvent, (n.d. A), System Models, available online System Models

7.1.4.4. Summary of recommendations for LCA approaches, allocation methods and system models

Best practice to follow:

- *The choice of LCA approach, allocation methods and system models should be consistent.*
    - *In most cases, the attributional LCA approach should be used, as this is the simpler of the two approaches, and is consistent with the other modelling choices recommended in this guideline.*
    - *For multi-product activities, the recommendation is to avoid allocation through system expansion.*
    - *For recycling at end of life, multifunctionality should be dealt with using closed-loop approximation in conjunction with system expansion.*
    - *The corresponding system model for the LCI datasets selected for the study should be consistent with the choice of LCA approach and allocation methods. Refer to Section 7.2.3.4 for more details.*

7.1.5 Modelling end of life and the waste management system in South Africa

A critical aspect of conducting an LCA study to comply with the EPR regulations, is to correctly model the end of life (EoL) of the identified products, given South Africa's current waste management system. This section makes recommendations to ensure the product EoL is accurately and consistently reported.

Figure 10 provides a schematic of the main lifecycle stages to consider when modelling product end-of-life. It is important to consider gathering accurate data on material inputs/outputs associated with the product system at the main EoL stages as per Figure 10, so to be able to accurately model South Africa's waste management system and current practices. Specifically:

- To correctly account for material collection, recycling and waste management:
    - In South Africa, approximately 71% (by mass) of municipal solid waste generated is collected ($W_{collection}$ as per Figure 10); while 29% is not collected or treated via formal waste management systems (Rodseth et al., 2020).
    - The uncollected waste should be treated as contributing to open dumping (W_{open_dump}), and ultimately contributing to pollution to the environment.
    - It is recommended that waste-stream specific splits between collected and uncollected waste be used if available; alternatively, the values for mixed waste (71% collected / 29% uncollected) should be used as a default.

- The split between waste going to "sanitary" and "unsanitary" landfill must also be specified ($W_{sanitary}$ and $W_{unsanitary}$ in Figure 10), as this will determine the extent to which the waste will be contained.
    - The best available data for municipal solid waste in SA, which was applied for Upper Middle Income countries in the Global Breaking the Plastic Wave study (Lau et al. 2020a, 2020b), as well as in the South African Pathways study (Stafford et al. 2022) following consultation with local experts, suggests that:

- In urban areas, 53% of waste is disposed of in sanitary landfill ($W_{sanitary}$ as per Figure 10), and 47% in unsanitary landfill ($W_{unsanitary}$)
- In rural areas, 28% of waste is disposed of in sanitary landfill landfill ($W_{sanitary}$), and 72% in unsanitary landfill ($W_{unsanitary}$).

  - It is recommended that the best available estimates of the splits between sanitary vs. unsanitary landfill for the waste stream in question be used, where available.

- Open-burning of waste is prevalent in South Africa, but there is no official country specific data available.
  - Based on Wiedinmyer et al. (2014), the Breaking the Plastics Wave study assumed that open burning of collected plastic waste globally is 13%, while the open burning of uncollected waste in residential areas is 60% (Lau, et al., 2020b).
  - To correctly account for open burning, it is recommended that the best available estimates for the waste stream in question be used. Alternatively, 60% (by mass) of the flow named W_{open_dump} and 13% of the flow named $W_{unsanitary}$ (as per Figure 10) should be used as a default.

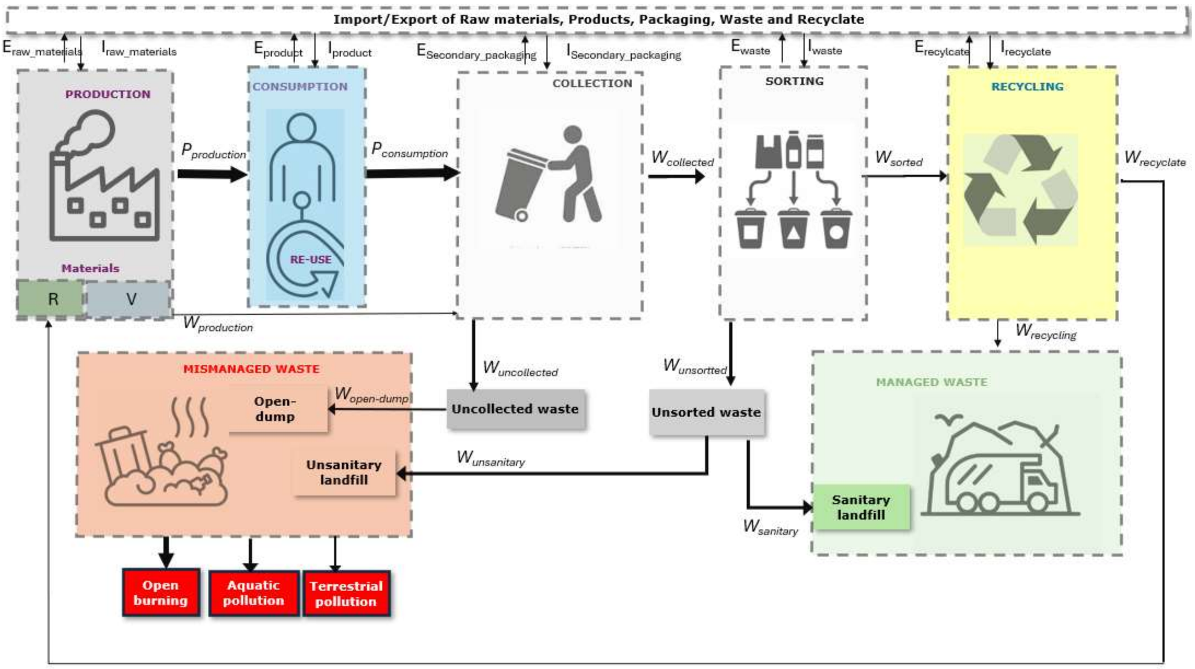

Figure 10: Schematic of main End of Life stages. 'P' refers to the product stream, 'W' refers to the waste stream, 'E' refers to exports and 'I' refers to Imports (Source: Authors)

Ideally, a standard use of these parameters in accounting for the EoL stage of a product is needed to ensure transparency and improve the consistency of efficiency and performance indicators. It is important to clearly state the parameters used (as per Figure 10) when calculating the Collection rate, Recycling rate, Recycling efficiency, Recyclate content, and Sanitary landfill treatment**.**

Finally, it is important to model the corresponding dataset for materials collection and recycling in the LCA study to evaluate the associated burdens.

7.2 Inventory Analysis

The inventory analysis stage involves data collection and modelling.

7.2.1 Data collection

Data collection involves the gathering of data for significant input and output flows associated with processes within the defined system boundary. This includes both physical flow data (e.g. a process requires *x* kg of material and *y* MJ of energy); as well as emissions released for each flow.

It is useful to differentiate between the '**foreground' and 'background'** of the product system. The foreground system refers to the direct operations of the primary process of interest. The background system refers to the supporting upstream and downstream processes within the value chain (e.g. electricity, transport, infrastructure etc.).

It is important to ensure that all foreground and background data are methodologically consistent (i.e. based on the same system model, preferably from the same database source, and with the same level of completeness), so as to meet the overall quality requirements of the assessment (ILCD, 2010).

A distinction can also be made between **primary and secondary data**. For specific processes, data measurements at the operational site in question (primary data) is the preferred option (ILCD, 2010). In practice, a range of other data sources (secondary data) may be utilised to cross-check or fill in missing data. These include process engineering and stochiometric models, product specifications, patents, etc. For secondary background inventory datasets; it is recommended to use pre-verified data, such as those obtained from national and international LCA databases (see Table 2); as well-documented third-party datasets support quality assessment and ease the review process.

Box 5 explains the important concepts of LCA databases and Life Cycle Inventory (LCI) datasets.

Box 5: What is an LCA Database? And an LCI Dataset?

An **LCA database** is a generic name for a database that contains data/information that can be used in an LCA study. It is an organised collection of digital Life Cycle Inventory (LCI) datasets covering a wide range of processes and product systems, and organized in such a way that users can easily search for and retrieve the datasets they need for their specific LCA studies:

- It is a system to organise, store and retrieve LCI datasets that conforms to a common set of criteria; including methodology, format, review and nomenclature
- It allows for interconnection of individual datasets to create LCA models
- It has a database management system that allows data creation and maintenance, searches and other types of access.

Examples of such databases include the ecoinvent, Agri-footprint, and GaBi databases (see Table 2). These databases help ensure consistency and comparability in LCAs, by providing standardized data that follows the ISO 14044 requirements.

In contrast:

- A **dataset library** is a collection of datasets that may not conform to common criteria and do not allow for interconnections and common applications for LCA purposes;
- A **data hub** is an access point for data from different data providers, e.g. GLAD, openLCA nexus, etc.

A **Life Cycle Inventory (LCI) dataset** refers to a set of data that represents input and outputs associated with a particular process or product system, based on a specific functional unit, and contains the following information:

- Reference product (or service) upon which all other flows are normalised
- By products (and/or waste)
- Resources from the environment: e.g. water, land, mineral resources (and sometimes CO_2 and O_2 uptakes)
- Input from the 'technosphere', i.e. links to other datasets (e.g. electricity, fuels, etc.)
- Emissions to the environment:
    - Emissions to air, e.g. CO_2, SOx, NOx, and particulates
    - Emissions to water, e.g. phosphates and nitrates
    - Emissions to soil, e.g. heavy metals and pesticides.

LCI datasets are a key component for conducting LCA studies, as they provide the raw data needed to quantify a product's environmental impacts.

A number of LCA databases exist to support the modelling of LCA studies. These are often embedded within LCA software and tools. The Life Cycle Initiative provides a comprehensive list and interactive map (Interactive map of LCA databases - Life Cycle Initiative) of LCI datasets provided in different databases.

Table 2 give an overview of the most commonly used LCI databases (not an exhaustive list). Some databases have a national (e.g. USLCI, the AusLCI, etc) or sector-specific focus (e.g. GREET); while others are aggregated and provide datasets based on different system models to fit different purposes (e.g. ecoinvent). It should also be noted that **some LCA databases (notably ecoinvent) contain South African LCI datasets for certain sectors**. To explore the different data provided and the system models offered, refer to the specific websites indicated in Table 2.

Table 2: LCA Databases

Database	Description	Source
ecoinvent	Comprehensive LCA database with data on energy supply, resource extraction, material supply, and more	ecoinvent Centre (2023). ecoinvent database v4.0. Swiss Centre for Life Cycle Inventories. Available at: https://www.ecoinvent.org/
U.S. Life Cycle Inventory (LCI) Database	Provides access to complete LCI data for custom life cycle impact assessments	National Renewable Energy Laboratory (NREL) (2023). U.S. Life Cycle Inventory (LCI) Database. U.S. Department of Energy. Available at: https://www.lcacommons.gov/nrel/search
GaBi Database	Includes a wide range of international data across numerous industries	thinkstep (2023). GaBi Database. Sphera. Available at: https://www.gabi-software.com/
ELCD - European Life Cycle Database	Provides LCI data for key materials, energy carriers, transport, and waste management	Joint Research Centre (JRC) (2023). European Life Cycle Database (ELCD). European Commission. Available at: http://eplca.jrc.ec.europa.eu/ELCD3/
GREET	Focuses on transportation fuels and vehicle technologies	Argonne National Laboratory (2023). GREET Model. U.S. Department of Energy. Available at: https://greet.es.anl.gov/
IDEA - Inventory Database for Environmental Analysis	Offers Canadian specific LCA data	CIRAIG (2023). IDEA Database. Polytechnique Montreal. Available at: https://ciraig.org/en/idea/
AusLCI - Australian Life Cycle Inventory Database	Provides Australian specific LCA data	AusLCI (2023). Australian Life Cycle Inventory Database. Australian Life Cycle Assessment Society. Available at: http://www.auslci.com.au/

7.2.2 LCA software tools

Undertaking an LCA study requires data modelling, access to Life Cycle Inventory (LCI) data, as well as tools or software for managing the data and running the calculations. This section briefly summarises the most common software tools to carry out LCA studies.

Some software includes access to LCA databases (collections of LCI datasets); while in other cases, commercially available LCA databases have to be purchased separately and then installed/imported into the specific software tool. Table 3 provides a summary of widely used LCA tools and software, and some of their key features. For a more detailed and comprehensive list of LCA software, please refer to the EPLCA website. In most cases, it is likely that some training on the use of the selected tool will be required. Please refer to the software providers' webpages for further information.

Table 3: LCA tools/software (including web-based options)

Software	Format	Free trial available?	Includes LCI databases?	Applications	Source
Ecochain Mobius	Cloud-based	14-day	Yes	Product design	ecochain.com/mobius
Ecochain Helix	Cloud-based	No, but demo version is available	Yes		ecochain.com/helix
GaBi	To download	30-day	Yes	Packaging, Automotive	Product Sustainability Software & Data | Sphera
LCA Calculator	Cloud-based	14-day			LCA Calculator - Online Sustainable Design Software
Oneclicklca	Cloud-based	14-day		Construction sector	www.oneclicklca.com
openLCA	To download	Free software, but LCI databases have to be purchased separately	No, to download separately		www.openlca.org
SimaPro	To download	No, but a demo version can be downloaded	Yes		www.simapro.com
Umberto	To download	Free trial version to download	Yes		Life Cycle Assessment (LCA) Software | Umberto (ifu.com)
Brightway	To download	Free and opensource	No, to download separately		https://docs.brightway.dev/en/latest/

7.2.3 Choosing relevant LCI Datasets

Datasets for specific production processes usually include elementary flows from nature, emissions (in the form of substances released to the environment), and a series of datasets that model specific inputs, e.g.:

- the infrastructure required (chemical factory, paper mill, machinery, etc.)
- electricity production (either from a specific source or as a country grid mix)
- specific materials used in the process (e.g. lime, terephthalate, etc.).

As part of LCI modelling, a number of different datasets need to be used (either adapted from existing datasets available within an LCA database, or created ad-hoc); for each process that forms part of the product life cycle. Within the various LCA databases (see Table 2), datasets for each specific process are given a unique name, typically in one of the following formats:

Material/Product {Geography}| activity type | system model| process type/stage

OR:

Material/Product| production process/stage | {unit} | Geography | system model

When selecting a dataset, several choices must be made according to the specific material/product, the geography (country where the process occurs), etc. The sub-sections below provide guidance on each these components, and on how to select and utilise datasets to build LCA models.

7.2.3.1 Material/Product

The **Material/Product** refers to the actual material type which a product is made of – e.g. Glass, Lithium, Organophosphorus compound, etc.; or, in some instances, to the whole product – e.g. hairdryer, keyboard, passenger vehicle, photovoltaic panel, etc.

7.2.3.2 Geography

There is an important choice to be made regarding geography, i.e. the country to which the dataset pertains. Ideally, one should seek datasets which represent the geography of where that specific production process occurs.

Country codes (and subcodes) following ISO 3166 (ISO, 2020) are used in LCA databases and software tools to differentiate countries or regions where production processes occur. For example, in the ecoinvent database (ecoinvent Association, n.d. C):

- ZA = South Africa
- RoW = Rest of World
- GLO = Global

Error! Reference source not found. provides a decision-tree to be utilised when selecting a dataset for a production process occurring within South Africa. First and foremost, for processes occurring in South Africa, one should try to find a suitable South African (ZA) dataset for the process in question (see Box 7). In cases where no suitable South African datasets are available, an international (RoW and / or GLO) dataset can be selected as a proxy (see Box 6), and adapted to the local context. A full list of country codes can be found at the ISO online browsing platform[9].

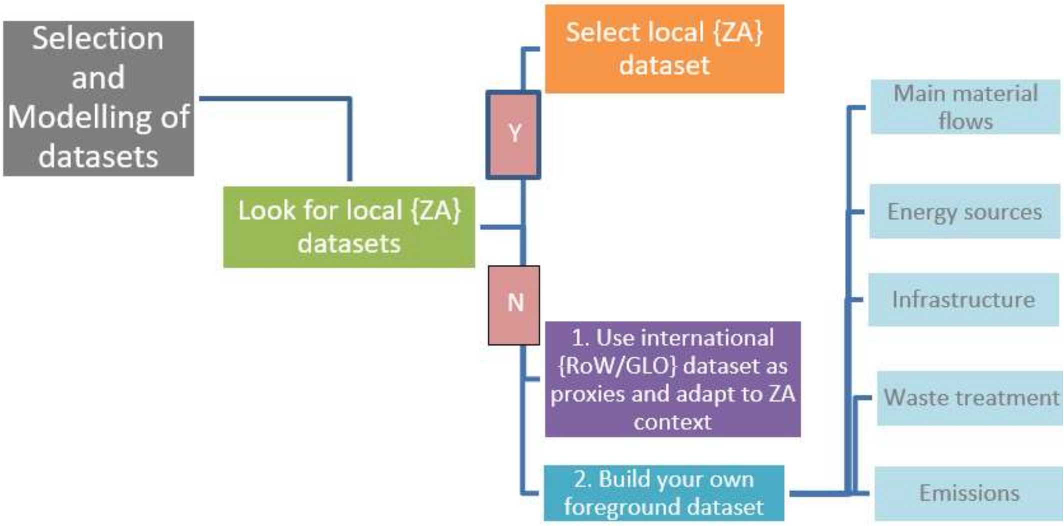

Figure 11: Decision tree for selecting an appropriate dataset to model a production process occurring in SA (Source: Authors)

Box 6: Which international dataset(s) to select?

A hierarchy for selecting the appropriate geography for background datasets is proposed below (see also Figure 11):

1. If available, select the dataset for the country where the specific process occurs (e.g. a South African dataset (country code ZA) for processes occurring in South Africa. For processes occurring elsewhere, use the relevant dataset for that country).
2. If not available, select a RoW (Rest of the World) dataset as a proxy.
3. If RoW proxies are not available, then the global (GLO) dataset for the specific process can be selected.

When using a proxy dataset (e.g. RoW or GLO); adaptation to the local context should be done as best as possible. Adaptation to the South African context can be done by replacing the following inputs within the dataset with relevant South African data:

- Utility inputs (e.g. electricity, water, transport modes etc.). The datasets for these inputs should be replaced with relevant South African datasets, e.g. for South African electricity production and water sources (taking into account whether water is an input from nature or from a processed water source (tap water), etc.).
- Main material inputs (datasets for raw material production; e.g. for aluminium sheets to produce cans; mineral inputs for fertilizer production; pulp production for paper mills, etc.).

[9] Online Browsing Platform (OBP) (iso.org)

- End of life. The ecoinvent database has datasets for a number of waste treatment scenarios in the SA context (see Box 7), including sanitary landfills, unsanitary landfills, open burning, and open dumping (which can be used to model informal disposal, litter, and leakage).

When a suitable dataset can't be found and/or adapted, the last option is to build an **ad-hoc (foreground) dataset** to model the production process of interest. As per Figure 11, a foreground dataset should consist of *Main material flows, Energy source (electricity and heat, if applicable), Infrastructure, Waste treatment(s) and Emissions.* This is to ensure that the foreground dataset has the highest possible level of completeness as the background datasets. This aspect is extremely important when carrying out LCA studies aimed at comparing different (material / design) options for the same product.

Box 7: South African LCI datasets

Some databases already include a number of South African datasets. In particular, the ecoinvent Association Database (ecoinvent, n.d. B) contains a growing number of South African datasets.

Figure 12 provides a snapshot of the sectors for which South Africa LCIs have already been published in the ecoinvent Association Database.

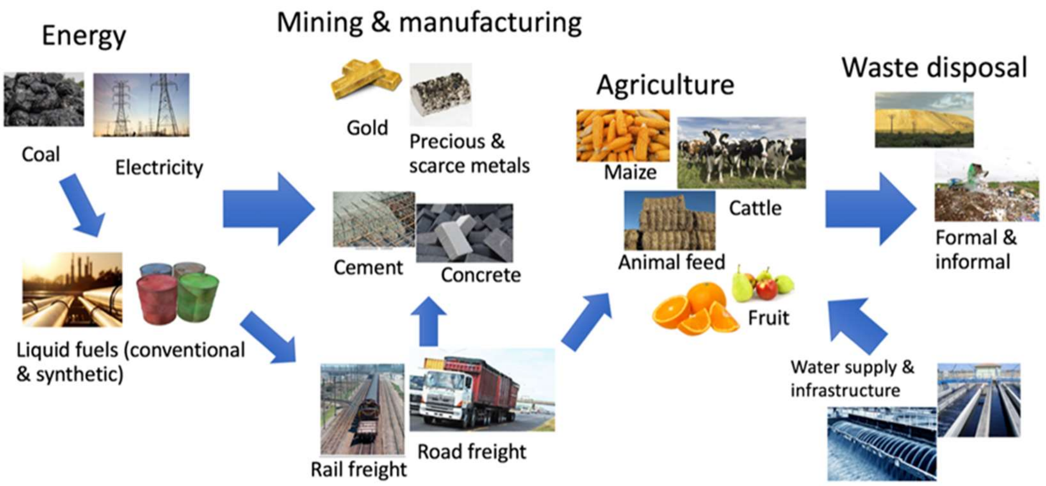

Figure 12: South African LCI datasets included and available in the ecoinvent Association Database

Best practice to follow:

- *As far as possible, it is recommended to make use of databases that provide datasets for production processes in the South African context.*
- *For each process, first check if a suitable background dataset exists for the country where the specific process occurs (e.g. ZA geography for process occurring in South Africa). If not:*
    - *Adapt an existing dataset (from a different geography, e.g. RoW or GLO), or*
    - *Build a foreground dataset by using a combination of primary data (preferably) and secondary data.*

7.2.3.3 Activity type

Different LCA databases provide different types of datasets for production processes at different stages of the production chain (e.g. during processing, etc.), that model how input materials are transformed into intermediate or final products. Some LCA databases also provide aggregated "market" datasets that provide a "blend" of how a product could be produced (e.g. a mix of technologies, a mix of transport modes etc.).

Thus, when possible and once the issue of geography has been resolved, a choice needs to be made regarding whether a **transformation process** or a **market process** should be selected:

- **Transformation processes** refer to activities that transform inputs into outputs. Transformation processes should be selected in cases where the production process to produce a specific (intermediate) material occurs within a specific local context.
- **Market processes** refer to activities involving the transfer of intermediate inputs or products from one transforming activity to another transforming activity, which consumes the intermediate product as an input. Examples of cases where market activities are appropriate include:
    - When inputs to a production process are imported from a number of countries, a market dataset will provide data for an "average product" supplied by the global market.
    - When the energy (electricity) is supplied by the national grid, a market activity that provides the national grid mix is recommended.
    - When a transport mode (e.g. road freight) is supplied by variety of technologies (e.g. trucks with different loading capacities), a market activity that provides the "average transport mode" is recommended.

Best practice to follow:

- *When data from a specific supplier is not available, or when there is a mix of technologies (usually for supporting datasets), it is recommended to use a market process.*

7.2.3.4 System model

Recall from Section 7.1.4 that LCA databases provide datasets based on various different system models to meet the needs of different types of LCA studies. Datasets associated with a specific system model reflect different assumptions regarding the supply (linking) and distribution of impacts between producers and consumers of products and services. The choices made regarding the LCA approach (attributional vs. consequential) and allocation method (see Section 7.1.4) inform the system model on which the selected LCI datasets should be based. These choices should all be consistent, and should be aligned with the goal and scope of the study.

Best practice to follow:

- *Datasets based on a system model aligned with the decisions made regarding LCA approach and allocation method, and with the goal and scope of the study, should be selected.*

- *As per Section 7.1.4, for LCA's conducted in line with the EPR Regulations, the recommendation is to apply the attributional LCA approach, and to avoid allocation through system expansion.*
- *In ecoinvent, the corresponding system model aligned with these recommendations is 'cut-off, by classification' (ecoinvent, n.d.). This model ensures that wastes are the producer's responsibility (in line with the system expansion approach), and that there is an incentive to use recyclable products (ecoinvent, (n.d.A)).*
- *If datasets based on a different system model are selected, this choice should be justified.*

7.2.3.5 Process type

The final aspect that needs to be taken into consideration when selecting a dataset is the **process type**. Two types of processes can be distinguished, namely **unit processes** and **system processes**:

- A **unit process** is the smallest element in the inventory analysis stage for which input and output data are quantified.
- **System processes** result from the compilation and quantification of inputs and outputs throughout a product's life cycle (ISO, 2006a).

The difference is that a system process is not an independent dataset, but is instead calculated from a number of unit processes. This distinction is graphically represented in Figure 13. Additionally, a unit process can be modified, which is beneficial when adaptation of the dataset to the local context is required (see Section 7.2.3.2).

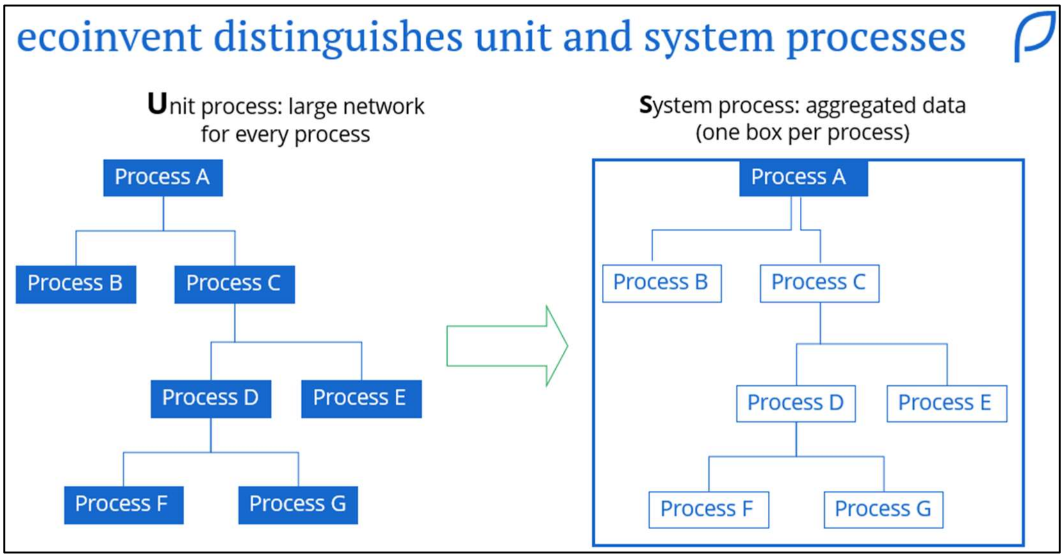

Figure 13: Difference between unit and system processes (Source: SimaPro Help Center[10])

Best practice to follow:

- *Use unit process datasets, as they are easier to adapt to the local context, as described in Section 7.2.3.2.*

[10] What are unit and system processes? (simapro.com)

7.2.4 Data quality and uncertainty

ISO 14044 (2006) emphasises that data quality must align with the study's goals and scope, and be reliable enough to support the conclusions. It highlights the importance of considering factors like temporal, geographical, and technological correlations, as well as precision and completeness.

ISO 14044 also addresses uncertainty in LCA results, arising from data variability and methodological choices. Practitioners are advised to identify, document, and analyze this uncertainty using appropriate statistical techniques and sensitivity analyses. The standard provides guidelines but doesn't prescribe specific methods or tools for managing data quality and uncertainty.

The EU Product Environmental Footprint (PEF) methodology provides guidelines for managing data quality and uncertainty to enhance the reliability and validity of LCA results. For example, specific primary data is suggested for processes with significant environmental impact. This refers to data obtained directly from a particular operation or process, such as energy usage in a manufacturing process. On the other hand, secondary data, like industry averages or database values, can be used for less impactful processes.

The PEF method also recommends **uncertainty analysis** to quantify the level of uncertainty in LCA results and to point out major sources of uncertainty. Techniques like Monte Carlo simulations can be used for this analysis, where random sampling is applied to model variability in input data, and to calculate its impact on the output results.

Finally, a **sensitivity analysis** is recommended by ISO 14044 to assess modelling and data uncertainties. Sensitivity analysis involves examining the influence of changing individual parameters on the overall LCA results. This helps highlight critical parameters that require highly reliable data, and helps to determine the overall robustness of the model.

Best practice to follow:

- *Any data limitations should be documented, as should any implications for the robustness and reliability of the results of the study.*
- *It is good practice to include Sensitivity Analysis to test the robustness of data inputs (see Section 7.4).*

7.3 Life Cycle Impact Assessment

The Life Cycle Impact Assessment (LCIA) stage involves translating LCI data on emissions and resource extraction (see Section 7.2) into potential environmental impacts, through the application of an LCIA Method.

Figure 14 illustrates the environmental impact assessment mechanism, from inventory flows to areas of protection (end-point damage categories). Generally, there are a number of different steps (some mandatory, some optional) involved in conducting the LCIA stage:

- **Classification** is the process of assigning inventory data to impact categories based on the potential environmental effect (e.g., greenhouse gas emissions are assigned to the 'climate change' impact category).
- **Characterization** is the process of calculating category indicator results by multiplying inventory results by characterization factors (which reflect the potential contribution of each substance to the environmental impact category).
- **Normalization** is an optional step which involves translating the results from the characterization into a common unit by dividing the category results by selected reference values. This allows for the comparison of the relative significance of different impact categories.
- **Grouping** is an optional step which involves sorting and possibly ranking the impact categories, to identify the most significant contributing factors to the environmental results.
- **Weighting** is an optional step which involves assigning weights to different impact categories based on their perceived relative importance.
- **Aggregation** to a single score is an optional step often used to simplify communication of the results. It involves aggregating the weighted impact category results to create a single overall score. However, aggregation to a single score can be controversial, as it is often based on subjective value choices regarding the weighting of different impact categories (see above), and can obscure differences between impact categories.

These steps are typically automated within the LCA software (see Section 7.2.2), rather than needing to be conducted manually.

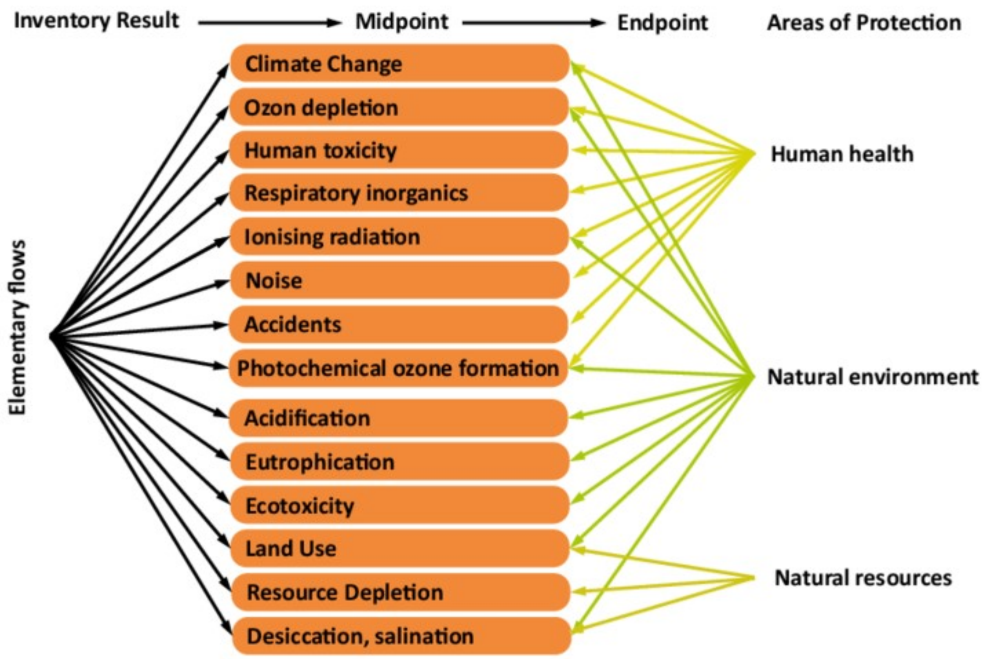

Figure 14: Life Cycle Impact Assessment mechanism.

An important distinction can be made between mid-point impact categories, and end-point damage categories (or areas of protection):

- **Mid-point impact categories** represent environmental impacts of a certain type, but don't necessarily predict the ultimate effects on human health or ecosystems.
- **End-point damage categories**, on the other hand, represent the potential damage to areas of protection such as human health, ecosystems, or resource availability, as a result of the environmental impacts. End-point indicators try to capture the "so what" of environmental impacts, expressing the ultimate damage in terms we can more intuitively understand, such as years of life lost, or species driven extinct. Estimating end-point damages requires the normalization and weighting steps described above.

A number of different **Life Cycle Impact Assessment (LCIA) methods** exist. These methods differ primarily in terms of the mid-point impact categories included, and in terms of their approach to classification, characterization, normalization, weighting and aggregation (see above).

Table 4summarises some of the main LCIA methods available for different types of LCA studies. Most LCA software tools (see Section 7.2.2) will include a number of such methods, which can be selected in order to calculate the LCIA results.

Table 4: Available LCIA methods for different types of LCA studies (non-exhaustive)

Purpose	Method	Associated Standard(s)
Full LCA	EF 3.0	European Commission, 2019. Environmental Footprint: Guide for the implementation of the EU; PEF_method.pdf (europa.eu); Circabc (europa.eu)
	ReCiPe 2016	Huijbregts et al. (2017) ; ReCiPe2016v1.1. | RIVM ; https://doi.org/10.1007/s11367-016-1246-y ; Goedkoop et al. (2009)
	GLAM1.0.2024.10 Global Guidance for Life Cycle Impact Assessment Indicators and Methods (GLAM)	Started by the Life Cycle Initiative in 2013, this project aimed to establish a comprehensive, consistent, and global Environmental LCIA method, including classification, midpoint and damage characterization, normalization, and weighting to assess the life cycle impacts of products and services on human health, ecosystems, and natural resources. It will also include initial characterization factors for plastic marine litter impacts on marine wildlife. The GLAM method was released in November 2024, but at the time of writing has not yet become available in LCA software. See https://www.lifecycleinitiative.org/global-life-cycle-impact-assessment-method-glam-launched-at-setac-europe-26th-lca-symposium/
	CML	Guinée, J.B., Gorree, M., Heijungs, R., Huppes, G., Kleijn, R., De Koning, A., Van Oers, L., Sleeswijk, A.W., Suh, S., De Haes, H.A.U., De Bruijn, H., Van Duin, R., Huijbregts, M.A.J., 2002. Handbook on life cycle assessment: Operational guide to the ISO standards. Kluwer Academic Publishers.
	TRACI	Bare, J., 2011. TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0. Clean Technologies and Environmental Policy, 13(5), pp.687-696.
	IMPACT 2000+	Jolliet, O., Margni, M., Charles, R., Humbert, S., Payet, J., Rebitzer, G., Rosenbaum, R., 2003. IMPACT 2002+: A new life cycle impact assessment methodology. The International Journal of Life Cycle Assessment, 8(6), pp.324-330.
Carbon footprint only	IPCC 2013 (100yr)	ISO 14067 and (SATS 14067:2013)
	IPCC 2013 (100yr including CO_2 uptake)	Accounting for the CO_2 uptake is relevant for the following standards: GHG protocol, ISO 14067 (SATS 14067:2013), PAS 2050
Water footprint Only	AWARE (to represent specific watersheds)	ISO 14046 (SANS 14046) Home - WULCA (wulca-waterlca.org)

A comparison of these methods suggests that most prioritize common impact categories such as climate change, ozone depletion, human toxicity, ecotoxicity, acidification, and eutrophication. However, there are specific areas where the methods diverge.

Both **Environmental Footprint (EF)** (European Commission, 2021; Fazio et al., 2018; Sala et al, 2018) and **ReCiPe** (ReCiPe, 2016, Huijbregts et al., 2017) are regarded as scientifically sound and robust methods, and incorporate a broad range of environmental impact categories. However, the two methods differ in a number of respects:

- While both marine ecotoxicity and terrestrial acidification are included in ReCiPe, neither are included in EF, due to issues with regionalisation, data availability and reliability.
- They also differ in terms of the use of spatially explicit assessments of water demands in relation to local water availability or water stress. While ReCiPe does assess water use, it does not address water scarcity or depletion, which is included in EF using the Available Water Remaining (AWARE) model (Boulay et al., 2018).

The EF impact assessment method has been developed as part of the Product Environmental Footprint (PEF) Guide (European Commission, 2021). Regarding normalization and weighting, the PEF Guide recommends normalization using European normalization factors, but global normalization factors are also available (Sala et al., 2017). Regarding weighting, PEF recommends equal weighting for simplicity, but this step is not mandatory. If weighting is used, results should be presented both with and without weighting to show the influence of this step.

The ReCiPe method also includes classification, characterization, normalization (using global normalization factors), and weighting. ReCiPe provides sets of weighting factors based on different perspectives (egalitarian, hierarchist, and individualist). The method also enables the aggregation of impact categories into a single score.

In summary, both methods (EF and ReCiPe) include the optional steps of normalization, weighting and aggregation to a single score. However, it is essential to understand the inherent subjectivity and potential loss of detailed information when undertaking these steps.

Impacts from plastic pollution are regarded as a notable omission from all LCIA methods, including EF and ReCiPe. As per Table 4; a more comprehensive, consistent, and global LCIA method has recently been developed through the Life Cyle Initiative; under the Global Guidance for Life Cycle Impact Assessment Indicators and Methods (GLAM)[11]. Unlike existing methods, the GLAM method will feature initial characterization factors for plastic marine litter impacts on marine wildlife.

Considering that many of the products identified under the EPR Regulations contain plastic, **the recommendation is to make use of GLAM method once it becomes available for use** within LCA software. In addition, GLAM has a global focus, and involved a process of reaching consensus on various methodological issues; including on the life cycle impacts of products on human health,

[11] Global Guidance for Life Cycle Impact Assessment Indicators and Methods (GLAM) - Life Cycle Initiative

ecosystem and natural resources; and eventually on a method to consistently combine these environmental impacts into an aggregated score.

In the meantime, in the context of the **EPR regulations**, which has a focus on the toxicity of the resulting post-consumer waste stream, the **ReCiPe** method is preferred to other methods such as EF, since it assesses a wider range of toxicity categories. However, when conducting a **PEF study** (for products exported to the EU), the **EF method** must be used.

Best Practice to follow:

- *It is recommended to use the GLAM method once it has become available for use within LCA software.*
- *In the meantime, the ReCiPe method is recommended. Specific recommendations for use of ReCiPe include:*
    - *For calculating midpoint scores, apply the hierarchist social perspective (ReCiPe midpoint (H)), which is based on the most commonly agreed policy principles with regards to timeframe and other issues.*
    - *Should the analysis be taken to endpoints (and Single Score), select the ReCiPe H/A (hierarchist, average weighting) weighting system.*
    - *In general, value choices made in the hierarchist version are scientifically and politically accepted.*
    - *The water footprint indicator in ReCiPe can be improved by using a water stress or depletion method for assessing water use impacts, namely AWARE (Available Water Remaining), which provides characterization factors for water use that account for regional water scarcity (https://wulca-waterlca.org/).*
- *When conducting a PEF study, the EF impact assessment method must be used.*
    - *Where normalisation and weighting are conducted (optional steps), all assumptions should be made transparent and explicit. The recommended global normalisation per capita values should be used (Sala et al., 2017), subject to any adaptions for South Africa.*
    - *If weighting and aggregation to a single score is carried out, the details of the method must be specified, and the default equal weighting, as recommend by the PEF method, should be used. Any variations, e.g. adaptation of normalization and weighting to the South African context to counterbalance its Eurocentric nature, should be transparent and made explicit.*
- *Should an LCA need to be done to meet export market requirements for a country outside of the EU, check specific country requirements regarding the LCIA method to be used.*
- *In cases where the study is being conducted to comply with both EPR and export requirements, it is possible to apply more than one LCIA method; as results based on different methods can easily be calculated by the LCA software.*

7.4 Interpretation

Finally, the Interpretation stage refers to the reporting and interpretation of the results of an LCA study. Importantly, in line with the iterative nature of an LCA study, the interpretation stage should also involve reviewing the choices made in previous stages of the LCA (see Figure 4), and making changes where necessary.

7.3.1. Presentation of results

Appropriate interpretation and presentation of LCA results are important steps for ensuring meaningful decision support. The results should ideally be presented in a user-friendly, systematic way to ensure ease of understanding.

Results can be presented and interpreted in a number of different ways, depending on the goal of the study:

- **Hotspot analysis and contribution analysis**
    - LCA results are generally presented in the form of pie- and bar-charts, tables, and Sankey diagrams.
        - **Sankey diagrams** are useful for visualization of areas of concern and for **hotspot analysis**, which involves identifying processes and flows which give rise to the highest environmental impacts. Sankey diagrams can also be supplemented by impact analysis tables.
    - The contribution of different inputs to the various impacts can also be viewed via impact assessment bar charts. These can also be utilised to ascertain dominant stages and flows within the overall assessment.
    - **Contribution analysis** is often the most informative way of presenting results for identifying hotspots. Hotspots could refer to *impact categories, life cycle stages, processes or elementary flows* which contribute most significantly to the overall environmental impacts.
    - Both Sankey diagrams and contribution analysis are useful for hotspot analysis, and will respond to the need of delineating a baseline environmental profile of the product(s) under assessment, highlighting areas of concern (e.g. carbon emissions, toxicity of the post- consumer waste stream generated, etc.).

- **Scenario analysis**
    - Scenario Analysis is the most informative way of comparing the environmental impact of alternative options (e.g. different product designs or different material options). When comparing different scenarios, scenario analysis can be used to assess the impact of different decisions on the overall environmental footprint of the product. The available software packages also provide facilities to perform scenario analysis by way of comparing product systems via bar charts.
    - Scenario analysis can be useful to understand if (for example) a different product design, material choice, or supply chain is able to respond to the requirements of Regulation 5, sub-regulation (1)(l) of the EPR Regulations. It allows comparison of the baseline environmental profile of the product (status quo scenario) with alternative scenarios; such as
        - a new design, delivery model (e.g. refill) or repair scheme to facilitate reuse
        - a new material to reduce the toxicity of the post- consumer waste stream
        - a new way to facilitate recovery (e.g. return schemes).

- **Sensitivity analysis**
    - Sensitivity analysis can be used to test the robustness of modelling choices and their sensitivity to uncertain factors. It involves assessing how LCA results change when input parameters (data) or assumptions are varied.
    - Specifically, it can help identify which data and assumptions have the most significant influence on the results. This can include parameters such as the choice of functional unit, system boundaries, allocation methods, impact assessment methods, and the quality or uncertainty of inventory data.
    - Sensitivity analysis can involve the 'one-at-a-time' method, whereby a single input parameter is altered to understand its influence on the outcome; or Monte Carlo simulations, which involve changing the input parameters based on their probability distributions and running the model multiple times to generate a range of outcomes. This helps to estimate both the most likely result and the degree of its possible variation (see Section 7.2.4).

Best practice to follow:

- *Given the requirements of Regulation 5, sub-regulation (1)(l) of the EPR Regulations, **scenario analysis** is recommended to compare alternative scenarios aimed at:*
    - *Minimisation of material used in the identified product;*
    - *Design of the product to facilitate reuse; recycling or recovery, without compromising the functionality of the product; and*
    - *Reduction of environmental toxicity of the resulting post-consumer waste stream*
- *It is good practice to carry our **contribution analysis** to identify the most relevant impacts and the lifecycle stages or processes that make the greatest contribution to overall impacts. The following is recommended:*
    - *The **most relevant impact categories** should be identified as all impact categories that cumulatively contribute at least 80% to the total environmental impact (Zampori et al., 2016).*
    - *The **most relevant life cycle stages** are the ones that together contribute at least 80% to any of the most relevant impact categories identified (Zampori et al., 2016).*
    - *The **most relevant processes** are those that collectively contribute at least 80% to any of the most relevant impacts (Zampori et al., 2016).*
    - *The **most relevant elementary flows** are defined as those elementary flows contributing cumulatively at least 80% to the total impact for each of the most relevant processes or categories identified (Zampori et al., 2016).*
- *It is good practice to use **sensitivity analysis** to test robustness of the results to data inputs (i.e. key parameters identified in the hot-spot analysis). However, in the context of this Guideline, sensitivity analysis to test methodological choices (e.g. different system boundaries, allocation rules and impact methods) is <u>not</u> recommended, to ensure the consistency and comparability of results among different LCA studies.*

7.4.2 Template for reporting

A possible template for compiling a report of an LCA study is provided in *Guideline 4 – Templates for LCA Reports and for Critical Reviews of LCA Studies.*

7.4.3 Critical review

Reviews of Life Cycle Assessment (LCA) studies are conducted in accordance with ISO 14044 (ISO, 2006b), where it is stated that "*In order to decrease the likelihood of misunderstandings or negative effects on external interested parties, a panel of interested parties shall conduct critical reviews on LCA studies where the results are intended to be used to support a comparative assertion intended to be disclosed to the public*." Thus, **critical reviews of LCA studies are compulsory in cases when results will be communicated to the public domain, particularly in the case of comparative LCA studies, or when making environmental claims**.

The objective of the critical review process is to ensure that the LCA study is consistent with the standard to which the study refers. In most cases this would be the ISO 14040 series (see Section 6.2 and Table 1), although other national, product-specific or case-specific standards may also apply (Weidema, n.d.; ISO/TS 14071:2024). Refer to Guideline 2 for a full list of possible standards.

Usually the need for a critical/peer review of the study is stated in the Goal and Scope definition, where the following must be clearly defined:

- *The intended application;*
- *The reason for carrying out the study;*
- *The intended audience* – it must be stated if the LCA study is for internal use, or if it is intended for public communication (including for environmental claims). If the latter, then a critical review is required; and the need for a Critical Review step must be clearly stated in the report.

A possible template for presenting a peer review of an LCA study is provided in *Guideline 4 – Templates for LCA Reports and for Critical Reviews of LCA Studies.*

If a critical review of the study is needed; an independent, third party (external) LCA expert or practitioner must be identified. The reviewer must have adequate professional knowledge of both the LCA framework and the specific product type / sector which is investigated by the LCA study. The reviewer should also be independent, i.e. "*should not have business ties with the practitioner and/or any commercial interests in the topic of the study*" (Weidema, n.d; ISO/TS 14071:2024).

In relation to the EPR Regulations, it is envisaged that LCA results will be communicated to either the relevant PRO or to the Department (DFFE), to ensure that the requirements for LCA studies in the EPR regulations have been met. In cases where results are also communicated to the broader public, particularly in the case of comparative studies; or when environmental claims are made on the basis of the results, a critical review is required.

Best Practice to follow:

- *In all cases, a review of the LCA study is recommended to ensure that the study is reliable, credible and correct.*
- *A critical review must be carried out whenever the study findings are to be made available to the public, particularly in the case of comparative studies; or when the results are used for making environmental claims.*

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ANNEXURE 1 - Environmental Product Declarations (EPDs) and Product Environmental Footprint (PEF)

As indicated in Section 6.2, a number of global initiatives have aimed at harmonising LCA practices, with the most significant among these relating to Environmental Product Declarations and the Product Environmental Footprint approach.

The development of **Environmental Product Declarations (EPDs)** is a significant advance. Based on LCA data, EPDs provide transparent and standardised information about the environmental impacts of products. EPDs are divided into three categories - Type I, Type II, and Type III.

- Type I EPDs are founded on third-party verification, and comply with international standards like ISO 14025. They provide exhaustive information about the environmental performance of a product, allowing consumers to make informed decisions based on dependable data.
- Type II EPDs, also known as self-declared EPDs, are founded on the manufacturer's own assessment, and are not verified by a third party. Despite the fact that they can still provide useful information, their dependability depends on the manufacturer's diligence and openness.
- Type III EPDs are compliant with the ISO 14025 standard. Sector-specific EPDs are created in accordance with particular Product Category Rules (PCRs), enabling greater comparability of similar products. Type III EPDs provide standardised information for a specific industry or product category, and are verified by an independent third party. Type Ill environmental declarations (ISO 14025: 2006) aim at providing quantified and third-party verified environmental data using predetermined parameters; and, where relevant, additional environmental information.

EPDs are produced based on LCA calculations (following ISO 14025), and provide a quantitative basis for comparison of products (goods or services). In addition, an EPD must be produced according to a specific set of Product Category Rules (PCRs) (see below), which provide calculation rules and guidelines to ensure all EPDs under the same product category report the same type of information. EPDs have a 5-year validity.

In practical terms, an EPD consists of two key documents:

- The underlying LCA report, a systematic and comprehensive summary of the LCA study to support the third-party verifier when verifying the EPD. This report is not part of the public communication.
- The public EPD document, which provides the LCA results and other EPD content as per ISO 14025.

Since EPDs are voluntary declarations of the life cycle environmental impact, having an EPD for a product does not necessarily allow comparison with alternatives (the EPD only reports on the environmental performance of the specific product assessed; not of alternatives). However, since an EPD is a third-party verified document, which gives the information credibility, it is suitable for procurement purposes.

Product Category Rules (PCRs) are a "*set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product category*" (ISO 14025:2006). A **product category** is a "*group of products that can fulfil equivalent functions*" (ISO 14025:2006). The aim of the PCRs is to achieve comparability in results between different producers of the same product.

ISO 14025 is based on ISO 14040/44, and deals with Type III environmental declarations, which contain quantified environmental information on the life cycle of a product, to enable product comparisons. ISO 14025 introduces PCRs; which are specific guidelines for the calculation of the environmental impact of products with similar characteristics. Their development follows the ISO/TS 14027 standard.

PCRs are subject to the administration of program operators. Examples of program operators are Environdec (located in Sweden, with an international focus), PlasticsEurope (the Association of Plastics Manufacturers in Europe), Institut Bauen und Umwelt (Germany), EPD-norge (Norway), UL Environment (United States) and JEMAI (Japan).

Guideline 3: Available PCR's and PEFCR's provides a comprehensive, yet non-exhaustive, list of PCRs already developed or under development/updating.

Table 5 provides a comparison between standard LCAs, EPDs and PCRs, for certain key features.

Table 5: LCA, EPD and PCR comparison

	Standard LCA (ISO 14040-14044)	**EPD (ISO 14025)**	**PCRs (ISO 14025 and ISO/TS 14027)**
Aim and Goal	LCA is a standardised methodology to evaluate the environmental impacts associated with all stages in the life cycle of a commercial product, process or service.	The goal of EPDs is to use verifiable and accurate information to encourage the demand for, and the supply of, products that have lower impacts on the environment.	The aim of PCRs is to set out a clear, user-friendly (LCA) methodology for products with similar characteristics; and thereby to ensure that EPDs are straightforward to compile, and that results are comparable.
Scope and level of prescriptiveness	In-depth analysis of the impacts of a product or service along the value chain. It may contain sensitive data (not for disclosure).	An EPD is a short version of a standard LCA report. It contains product information and LCA results only. EPDs have to follow product-specific rules to allow for consistent product information (comparability between products fulfilling the same function).	Tighter, more defined version of the LCA standard (pre-defined scope). Specifically, PCRs define: • Product functional unit • Life cycle stages to be included • Modelling considerations • Reporting requirements (general production information, background information/ data

			sources, environmental indicators).
Ease of communication		Simpler to read and easier to communicate.	Simplified communication for consumer to allow product comparisons.
Requirement for verification	Must undergo a peer review if results are to be communicated to a third party.	No need to be verified (but the LCA from which the EPD stems has to be third-party verified).	Product representation and agreement on PCRs and industry standard.
Uses	Used for a variety of purposes • *Companies (internal):* hotspot analysis aimed at addressing issues through product design or company policy • *Companies (external):* communicate to stakeholders, make EPDs • *Government and NGOs*: to inform policy and legislation • *Academics and researchers*: Research on new products/ prototypes; to inform policy development; education.	Used in communication; as for example Business-to- business (B2B) communication (green public procurement, tenders by private companies, etc.).	Product comparisons. Harmonisation of markets; B2B communications.
Application	Application can be tailored to purpose. Typically used for internal analysis and B2B product R&D. When used for external communication, must be independently reviewed.	EPDs can be created for a company-specific product; or for the average product of members of a branch organization.	B2B and B2C communication. Inform consumer choice and harmonise 'green claims' in the market.

Environmental declarations and claims (eco-labels) were created by private and public groups to address credibility and impartiality in environmental claims. However, there are over 544 eco-labelling schemes worldwide, and 231 in Europe alone, which are not comparable. The plethora of eco-labelling schemes and the lack of consistency, inter-operability and comparability has hindered the development of a single, coherent market for green products, created difficulties in the national reporting of environmental emissions and pollutants, and cast uncertainty on the validity of environmental claims.

The European Commission's *Action Plan on Sustainable Consumption and Production*, and *Building a Single Market for Green Products,* led to the development of a more standardized LCA methodology to facilitate improved assessment and communication of the environmental performance of products and organisations. The **Product Environment Footprint (PEF)** approach provides common LCA rules and criteria for data collection, impact assessment, and reporting. Through a multi-stakeholder process, the PEF methodology ensures robustness, transparency, and comparability of environmental claims, and has developed Product Environment Footprint Category Rules (PEFCRs) to improve the comparability of LCA studies on similar products.

Product Environmental Footprint (PEF) – and **Organisation Environmental Footprint (OEF)** – are LCA-based methods to measure and communicate the potential life cycle environmental impact of products (goods or services) and organisations, respectively. Together, they form the basis for the

EU Environmental Footprint. The PEF method outlines an improved common framework for all the steps and specific rules necessary to conduct an appropriate and comparable LCA. Its mission is to strengthen the (European) market for green alternatives, and ensure that environmental impacts are transparently assessed and, ultimately, reduced. Key features of PEF include:

- Common methodological approach to assess, display and benchmark the environmental performance of products, based on a comprehensive assessment of environmental impacts over the life cycle;
- Structured according to the same steps as an LCA (i.e. follows ISO 14040 & 14044), but provides further specifications necessary to achieve a higher degree of robustness, consistency, reproducibility, and comparability;
- Like Environmental Product Declarations (see above), PEFs can follow product/sector-specific **Product Environmental Footprint Category Rules (PEFCRs),** which have been developed for certain products, in collaboration with sector stakeholders.

Table 6 provides a comparison of LCA as according to the ISO standards, vs the PEF methodology, for various features of an LCA study.

Table 6: ISO LCA vs PEF comparison

Requirements	LCA	PEF
Functional unit (FU)	Choose FU that best captures the product function.	Must be defined in terms of what, how much, how long and how well.
System boundary	Chosen according to the objective and scope of the study: • Cradle-to-grave (full LCA) • Cradle-to-gate (production only) • Gate-to-gate • Gate-to-grave (waste management).	By default, covers cradle-to-grave.
Inventory analysis	Only general guidance, no rules provided.	Guidance for the collection and modelling of inventory data, including allocation rules and data quality requirements.
Impact assessment (IA)	Freedom to choose from different IA methods, to capture all relevant impacts of the product system	Default set of 16 impact categories (based on the Environmental Footprint (EF) LCIA method).
End-of-life (EoL)	EoL phase should be considered (not prescriptive).	Concrete approach and formula for EoL processes (Circular Footprint Formula).
Interpretation	Hotspot analysis, sensitivity analysis and recommendations.	Robustness assessment; results reported for total life cycle and total life cycle excluding use stage.
Verification and validation	Optional; critical review required for comparative assertions disclosed to public.	Mandatory.
Other Aspects		
LCA Approach	Attributional and Consequential LCA.	Attributional LCA only.
Focus	Allows for comparison and hotspot analysis (product/process/service improvement).	Benchmarking focused.
Data / Methods	Any LCA database can be used. LCA can be extended to include social and socio-economic aspects (S-LCA and LCSA).	European-centric data and method. New/cutting-edge data not represented in EF datasets.

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